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Operations and Modeling Analysis

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PREFACE

This report describes the research performed under NASA (LaRC) Grant NNL04AA80G, titled Operations and Modeling Analysis. This research is directed toward improving and updating the cost data, cost estimating relationships, methodology, and implementation of the Logistics Cost Model (LCM) completed under a previous contract. The objective of this research is to provide an operation and support cost analysis capability to support the conceptual design and evaluation of space transportation systems.

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1. INTRODUCTION

1.1 General

The University of Dayton is pleased to submit this report to the National Aeronautics and Space Administration (NASA), Langley Research Center, which outlines the research completed in updating and improving existing operations and support (O&S) costing methodologies. Details concerning the baseline Reliability and Maintainability Model (RMAT) and the O&S costing model (LCM) may be found in previous reports accomplished under a previous grant (NASA Research Grant NAG-1-1327) as well as NASA Langley Research Center contract NAS1-99148, titled Operations Modeling and Analysis. In the process of completing this research, new cost data were obtained and analyzed, new costing methodologies were developed, and a revised costing model was completed.

1.2 Background

The Reliability and Maintainability Analysis Tool (RMAT) provides NASA the capability to estimate reliability and maintainability (R&M) parameters and operational support requirements for proposed space vehicles based upon relationships established from both aircraft and Shuttle R&M data. RMAT has matured both in its underlying database and in its level of sophistication in extrapolating this historical data to satisfy proposed mission requirements, maintenance concepts and policies, and type of vehicle (i.e. ranging from aircraft like to shuttle like). However, a companion analyses tool, the Logistics Cost Model (LCM) has not reached the same level of maturity as RMAT due, in large part, to nonexistent or outdated cost estimating relationships and underlying cost databases, and it's almost exclusive dependence on Shuttle operations and logistics cost input parameters. As a result, the **full** capability of the RMAT/LCM suite of analysis tools to take a conceptual vehicle and derive its operations and support requirements along with the resulting operating and support costs has not been realized.

To date, several models and various procedures have been developed to address different aspects of the conceptual design process. Collectively, these efforts have provided an analytical approach for predicting operational capabilities and supportability of proposed vehicles. These models include the Reliability and Maintainability (R&M) model developed during the first two years of a previous grant, a discrete event computer simulation model developed by NASA (LRC), the logistics cost model developed by Rockwell, the shuttle R&M data study completed by Martin Marietta, and various O&S cost estimating relationships identified and developed as part of the most recent research effort. Much of these efforts are based upon comparability analysis with aircraft systems along with comparisons with corresponding space shuttle reliability and maintainability parameters, turn-around times, operational procedures, and operations and support costs. Although designed to answer different questions, these models and procedures must be consistent with one another as part of a study effort. For example, the R&M model input/output can be used by the O&S costing methodology to establish many of the "cost drivers." In addition, the R&M model can provide many of the input parameters needed by the simulation model. In fact, the R&M model was originally conceived to provide failure times and repair times for use in computer simulation models. However, the scope of the R&M model has increased significantly beyond this one objective. It also provides estimates for vehicle turn times, manpower requirements, and initial spares requirements using derived or specified R&M parameters and crew size information. NASA has identified both a cost element structure (CES) and a vehicle work breakdown structure (WBS) which provides a common framework for

the development of R&M parameters and life cycle costing that can be used consistently among these models. The next logical step in this evolutionary development of quantitative tools and techniques is to integrate these models within this common framework. Once this has been accomplished, then a complete and cohesive set of procedures for performing analyses can be developed. This will insure all models and procedures will be based upon common vehicle processes, WBS's, CES's, and design and performance factors.

1.3 Research Statement

The objective of this research is to establish cost estimating relationships and costing methodologies for use in establishing the operation capability and supportability of proposed space vehicles. The expectation is that these relationships and methodologies would then be incorporated into existing computer models thereby enhancing their usefulness as an analysis tool.

1.4 Benefit

Decisions to develop, procure, and support a new Space Transportation System (STS) are based on many factors with the projected cost of the system over its operational lifetime being one of the more significant. Operating and support costs normally constitute a major portion of a system's life-cycle cost and, therefore, are critical to the evaluation of each alternative STS. Accurate and easily obtainable cost estimates are then essential.

1.5 Scope

This research was limited to those subsystems that comprise the Work Breakdown Structure (WBS) used in the RMAT. Cost estimating relationships and costing methodologies are applied either at the subsystem level or the vehicle level depending upon the cost category. Only operational and support costs as identified by the NASA Cost Element Structure (CES) have been addressed. In general, operations and support costs are the costs of operating, modifying, maintaining, supplying, training, and supporting a system throughout its deployed life. Initial R&D and Procurement or acquisition costs are not considered, however, reoccurring R&D has been addressed. Initial (non-reoccurring) costs are only partially covered.

1.6 Assumptions

The following assumptions have guided the approach used in developing an overall costing methodology:

- RMAT remains basically unchanged other than modifications needed to support the costing model.
- RMAT will execute first and will provide much of the input to the costing equations.
- The Shuttle Access to Space costing exercise updated to reflect FY05 costs remains relevant.
- Air Force O&S aircraft and Space Command costs are the most relevant alternative costs available for estimating (conceptual) manned space vehicle costs.
- Manned space vehicle costs will likely fall somewhere between Shuttle and aircraft O&S costs.

1.7 Approach

The general approach for generating cost estimates is based upon the RMAT methodology and depends upon the RMAT model for much of the input. While the cost model can be run without first executing RMAT, it would require considerably more input on the part of the user. The RMAT philosophy of producing weighted average R&M parameters using aircraft based estimating equations and prorated shuttle values is duplicated to the extent possible in the proposed methodology. In developing cost estimates, the following guidelines were used:

- To the extent possible, input and output data is obtained from RMAT minimizing the amount of additional input.
- Shuttle cost estimates are scaled similar to the parametric mode in RMAT
- Aircraft cost estimating relationships are kept as simple as possible and are at the same level as RMAT and normally consist of the same "driver" variables as RMAT.
- Consistent with RMAT, both Shuttle based estimates and aircraft based estimates are derived and weighted averages computed.

2.0 DATA ANALYSIS AND METHODOLOGY

2.1 General

Operating and Support costs are the cost of personnel, material, and facilities of both a direct and indirect nature required to operate, maintain, and support the use of the system over its design life. Cost data pertaining to this research focused on two distinct sources: (1) identifying and obtaining relevant costs pertaining to the Shuttle program, and (2) collecting and analyzing Air Force (AF) O&S cost data pertaining to major aircraft and launch systems. This approach provided consistency with the companion RMAT model in which the reliability and maintainability (R&M) data sources consist of Shuttle data and AF REMIS (Reliability and Maintainability Information System) data. One innovative approach used in the costing methodology that also mirrors the RMAT model is the ability to perform a weighted average of costs derived from both data sources.

The primary source of Shuttle cost data was the 1994 Access to Space study that provided Shuttle reoccurring costs for that year covering 8 missions. The cost data was adjusted to reflect fiscal year 2005 costs and then compared to current NASA budget activity and other recent Shuttle program estimates.

The primary sources of cost data for aircraft were obtained from the Air Force Instruction (AFI) 65-503, US Air Force Cost and Planning Factors and the Air Force FY 2005 budget estimate. The Requirements Management System (RMS D200A) was utilized for inventory spares cost data.

2.2 Cost Element Structure

A cost element structure (CES) establishes a standard vocabulary for identifying and classifying the costs of a system. The NASA Cost Element Structure displayed in Table 2-1 provided the framework for identifying sources of cost data, establishing costing methodologies, and computing the life cycle O&S cost.

Cost Element	Cost Element
2.1 Concept Development*	2.3.2.3 Spares
2.2 Acquisitions*	2.3.2.4 Expendables
2.3 Operations and Support Cost	2.3.2.5 Consumables
2.3.1 Operations	2.3.2.6 Inventory Management & Warehousing
2.3.1.1 Refurbishment	2.3.2.7 Training
2.3.1.2 Organizational Maintenance	2.3.2.8 Documentation
2.3.1.3 Processing Operations	2.3.2. 9 Transportation
2.3.1.4 Integration Operations	2.3.2.10 Support Equipment
2.3.1.5 Payload Operations	2.3.2.11 ILS Management
2.3.1.6 Transfer	**2.3.3 System Support**
2.3.1.7 Launch Operations	2.3.3.1 Support
2.3.1.8 Mission	2.3.3.2 Facility O&M
2.3.1.9 Landing/Recovery/Receiving	2.3.3.3 Communications
2.3.1.10 Non-nominal Operations	2.3.3.4 Base Operations
2.3.2 Logistics Support	**2.3.4 Program Support**
2.3.2.1 Depot Maintenance	**2.3.5 R&D**

Cost Element	Cost Element
2.3.2.2 Modifications	2.4 Program Phase-out*

Table 2-1 Cost Element Structure
*Not addressed in this study

2.3 Personnel Costs and Turnover Rates

Several cost elements are determined in part by computing personnel levels and then applying an average annual salary. Default values are identified below and reflect a fully burdened salary. Currently 69 percent of NASA's workforce is comprised of GS 13, 14, and 15 employees.[1]

General Schedule	FY 2005	General Schedule	FY 2005
GS-01	27,154	GS-10	69,831
GS-02	30,121	GS-11	76,721
GS-03	33,320	GS-12	91,952
GS-04	37,404	GS/GM-13	109,347
GS-05	41,853	GS/GM-14	129,218
GS-06	46,650	GS/GM-15	151,999
GS-07	51,840	ES-Minimum	148,419
GS-08	57,408	ES-Maximum	223,698
GS-09	63,408		

Table 2-2 Civilian Standard Composite Pay Rates by Grade[2]
Source: AFI 65-503 Table 26-1

Officer	Annual	Enlisted	Annual
O-10	$229,854	E-9	$106,796
O-9	$223,771	E-8	$91,029
O-8	$207,455	E-7	$79,777
O-7	$186,544	E-6	$68,886
O-6	$171,019	E-5	$59,451
O-5	$150,565	E-4	$48,288
O-4	$131,923	E-3	$41,362
O-3	$98,448	E-2	$38,280
O-2	$83,503	E-1	$35,162
O-1	$72,337		

Table 2-3 FY2005 Standard Composite Rates
Source: AFI 65-503 Table A20-1

From the above table the default costs in Table 2-4 are used for determining personnel costs.

Personnel Category	Rating	Fully burdened annual salary
Technician (Maintenance)	GS-07 / E-4	(51,840 +$48,288)/2 ≈$50,000
Management or Professional (engineer)	GS/GM-14	$129,218

[1] http://nasapeople.nasa.gov/workforce/grade/present.htm
[2] Averages of the civilian payroll costs financed by Air Force O&M Appropriation 3400. Included are locality pay, overtime, holiday, night differentials, incentive awards and all other personnel compensation above the basic rates such as retirement, health benefits, life insurance, and quarters or uniform allowances.

Flight or mission crew member	O-5	$150,565
Security	E-4	$48,288
Technician (non-maintenance)	GS-09 / E-6	($63,408 + $68,886) /2 = $66,147

Table 2-4 Default Personnel Costs

	JSC	KSC	MSFC	SSC	ARC	DFRC	LARC	GRC	GSFC	HQ	IG	NASA
Avg Attrition	3.8%	2.7%	2.2%	3.9%	4.2%	6.0%	3.8%	2.5%	4.0%	6.4%	9.3%	3.7%
With transfer	4.20%	3.4%	2.5%	6.1%	4.7%	6.7%	4.4%	2.7%	4.6%	7.1%		4.64%

Table 2-5 NASA attrition rates (2001-2003)
Source: http://nasapeople.nasa.gov/workforce/hires/attrition.htm

From Table 2-5, a personnel turnover rate of 4.64 percent is used as a default rate.

2.4 Data Summary

2.4.1 Shuttle Data

Table 2-6 shows the default values used in the Logistics Cost Model (LCM) that were based upon the 1994 *Access to Space* study and sized for 8 Shuttle missions per year. Costs have been inflated to reflect FY2005 values[3].

Cost Element	Cost per flight*	Percent	Annual Cost
2.3 Operations and Support Cost	**$793.04**		**$6,344.36**
2.3.1 Operations	**$84.62**		**$676.96**
2.3.1.1 Refurbishment	$0.00	0.000%	$0.00
2.3.1.2 Organizational Maintenance	$21.88	2.758%	$175.01
2.3.1.3 Processing Operations	$1.52	0.191%	$12.14
2.3.1.4 Integration Operations	$0.75	0.095%	$6.02
2.3.1.5 Payload Operations	$7.51	0.947%	$60.10
2.3.1.6 Transfer	$0.00	0.000%	$0.00
2.3.1.7 Launch Operations	$12.16	1.533%	$97.25
2.3.1.8 Mission	$38.18	4.814%	$305.42
2.3.1.9 Landing/Recovery/Receiving	$2.65	0.335%	$21.23
2.3.1.10 Non-nominal Operations	$0.00	0.000%	$0.00
2.3.2 Logistics Support	**$247.37**		**$1,978.95**
2.3.2.1 Depot Maintenance	$13.66	1.723%	$109.29
2.3.2.2 Modifications	$1.07	0.135%	$8.57
2.3.2.3 Spares	$64.72	8.161%	$517.77
2.3.2.4 Expendables	$148.07	18.671%	$1,184.53
2.3.2.5 Consumables	$2.63	0.331%	$21.02

[3] All historical inflation factors used in this study were obtained from the NASA2003 Inflation Factors worksheet.

Cost Element	Cost per flight*	Percent	Annual Cost
2.3.2.6 Inventory Management & Warehousing	$11.54	1.456%	$92.35
2.3.2.7 Training	$2.47	0.312%	$19.80
2.3.2.8 Documentation	$1.66	0.209%	$13.27
2.3.2. 9 Transportation	$0.94	0.119%	$7.55
2.3.2.10 Support Equipment	$0.46	0.058%	$3.67
2.3.2.11 ILS Management	$0.144	0.018%	$1.15
2.3.3 System Support	**$138.61**		**$1,108.84**
2.3.3.1 Support	$66.19	8.346%	$529.51
2.3.3.2 Facility O&M	$52.97	6.680%	$423.79
2.3.3.3 Communications	$14.67	1.850%	$117.35
2.3.3.4 Base Operations	$4.78	0.603%	$38.27
2.3.4 Program Support	**$116.98**	14.751%	**$935.85**
2.3.5 R&D	**$205.48**	25.910%	**$1,643.83**

Table 2-6 Shuttle Costs (FY05 $M) (Source: *Access to Space* study)
*Based upon 8 flights per year

2.4.2 Validation of Shuttle Data

The FY 2006 NASA budget request for the Shuttle program is **$4,530.6** million.[4] This budget will support five Space Shuttle missions and planning for the phase-out of the Space Shuttle program in 2010. Since many of the Shuttle program costs are fixed and do not vary with the flight rate[5], an attempt was made to determine for each CES whether it was predominately flight rate driven or not.[6] This resulted in the costs shown in Table 2-7.

Cost Element	Cost per flight	Annual Cost
2.3.1.2 Organizational Maintenance	$21.88	
2.3.1.3 Processing Operations	$1.52	
2.3.1.4 Integration Operations	$0.75	
2.3.1.5 Payload Operations	$7.51	
2.3.1.6 Transfer	$0.00	
2.3.1.7 Launch Operations	$12.16	
2.3.1.8 Mission*		$305.42
2.3.1.9 Landing/Recovery/Receiving	$2.65	
2.3.2.1 Depot Maintenance		$109.29

[4] Reference: National Aeronautics and Space Administration President's FY 2006 Budget Request
[5] For example, the *Report of the Space Shuttle Competitive Sourcing Task Force* [xx] states "the costs of operating the Shuttle have not varied significantly with changes in the flight rate. Thus, if NASA maintains the current Shuttle infrastructure, curtailing flights will not lead to major cost savings."
[6] This distinction between fixed and variable costs is accomplished at a lower breakdown of the cost categories in Chapter 3 thereby resulting in a more accurate cost analysis.

Cost Element	Cost per flight	Annual Cost
2.3.2.2 Modifications		$8.57
2.3.2.3 Spares	$64.72	
2.3.2.4 Expendables	$148.07	
2.3.2.5 Consumables	$2.63	
2.3.2.6 Inventory Management & Warehousing		$92.35
2.3.2.7 Training		$19.80
2.3.2.8 Documentation		$13.27
2.3.2. 9 Transportation	$0.94	
2.3.2.10 Support Equipment		$3.67
2.3.2.11 ILS Management		$1.12
2.3.3.1 Support		$529.51
2.3.3.2 Facility O&M		$423.79
2.3.3.3 Communications		$117.35
2.3.3.4 Base Operations		$38.27
2.3.4 Program Support		$935.85
2.3.5 R&D		???
Sum	$262.83	$2,598.26
Total for 5 missions		$3,912.40

Table 2-7 Estimated Shuttle Costs for 5 flights
* It is assumed that mission planning including crew and staff training is continuous on-going activity.

If the R&D costs are included then the total for 5 Shuttle missions becomes $5,556.23. It is unlikely that the FY2006 proposed budget includes over $1600 million for R&D when the Shuttle program is to be phase-out. Assuming that the R&D costs are replaced by a smaller phase-out cost, the FY2006 budget of $4530 million and the Access to Space estimates are somewhat in agreement.

The Report of the Space Shuttle Competitive Sourcing Task Force provides another estimate of the Shuttle program based upon an FY2003 snapshot. Although the cost breakdown shown in Table 2-8 differs from the CES used in this study, the total program cost adjusted for FY 2005 dollars also supports the Access to Space cost estimate minus the R&D costs. Six flights were projected in the FY 2003 budget.

Function	FY03 Cost	Percent	FY05 Cost
Flight hardware & logistics	$1,680M	44.2%	$1,747M
Ground processing & operations	$600M	15.8%	$624M
Crew support, training & operations	$70M	1.8%	$73M
Flight operations	$210M	5.5%	$218M
Data communications	$40M	1.1%	$42M
Sustaining engineering & improvements	$290M	7.6%	$302M
Facility management & engineering	$120M	3.2%	$125M
Program management	$510M	13.4%	$530M
Program integration	$200M	5.3%	$208M
Flight safety & assurance	$80M	2.1%	$83M
Total	$3,800M		$3,951M

Table 2-8 FY03 Estimate of the Shuttle Program Cost (Source: "Alternate Trajectories, Options for Competitive Sourcing of the Space Shuttle Program," Report of the Space Shuttle Competitive Sourcing Task Force, December 2002)

Fiscal Year*	Request ($M)	Fiscal Year	Request ($M)
FY1992	4,312.5	FY1998	2,977.8
FY1993	4,128.0	FY1999	3,059.0
FY1994	4,196.1	FY2000	2,986.2
FY1995	3,324.0	FY2001	3,165.7
FY1996	3,231.8	FY2002	3,283.8
FY1997	3,150.9	Average	3,437.80

Table 2-9 Space Shuttle Appropriations FY1992-FY2002
NASA budget requests in then year dollars
(CRS Report for Congress, February 13, 2003)

The NASA budget requests in Table 2-9 for the years shown do not include R&D costs. Table 2-10 displays these same budget requests in FY2005 dollars. There was an average of 6 flights per year from FY92 to FY02. Computing an annual cost from Table 2-7 for 6 flights resulted in an annual cost of $4.175 M which compares very favorably with the average budget request over the time period identified in Table 2-10.

Fiscal Year	Request ($M)	Fiscal Year	Request ($M)
FY1992	$5,907.86	FY1998	$3,523.88
FY1993	$5,428.72	FY1999	$3,548.29
FY1994	$5,352.36	FY2000	$3,353.19
FY1995	$4,132.50	FY2001	$3,441.19
FY1996	$3,919.88	FY2002	$3,482.51
FY1997	$3,768.99	Average	$4,169.03

Table 2-10 Space Shuttle Appropriations in FY05 $M

2.4.3 Aircraft Data Sources

Several different sources of Air Force cost data were utilized. Table 2-11 summarizes the primary source(s) for each cost element.

Cost Element	Data / Estimation Source	Method used*
2.3.1.1. Refurbishment	Prevail Model[7]	CER
2.3.1.2 Organizational Maintenance	RMAT / AFI 65-503**	ECE / CER
2.3.1.3 Processing Operations	AF Budget/Space Prgm	ANA / CER
2.3.1.4 Integration Operations	AF Budget/Space Prgm	ANA / CER
2.3.1.5 Payload Operations	Hypervelocity Aerospace Vehicle cost study	CER

[7] The Prevail Model provides for design engineering, test and evaluation, and production costs broken down by 15 major subsystems

Cost Element	Data / Estimation Source	Method used*
2.3.1.6 Transfer	n/a	
2.3.1.7 Launch Operations	AF Budget/Space Prgm	ANA / CER
2.3.1.8 Mission	AFI 65-503	ECE / CER
2.3.1.9 Landing/Recovery/Receiving	n/a	
2.3.2.1 Depot Maintenance	AFI 65-503	CER
2.3.2.2 Modifications	AFI 65-503 /ACSC study	CER
2.3.2.3 Spares	D200A (RMS)	CER
2.3.2.4 Expendables	Access to space	ANA
2.3.2.5 Consumables	Default values	ECE
2.3.2.6 Inventory Management & Warehousing	A-76 standard	ECE
2.3.2.7 Training	AFI 65-503	ANA
2.3.2.8 Documentation	Hypervelocity Model	CER
2.3.2. 9 Transportation	AFI 65-503	CER
2.3.2.10 Support Equipment	AFI 65-503	CER
2.3.2.11 ILS Management	Logistics Cost Model	ECE
2.3.3.1 Support	AFI 65-503	CER / ANA /ECE
2.3.3.2 Facility O&M	AFI 65-503	CER / ANA
2.3.3.3 Communications	AFI 65-503	CER / ANA
2.3.3.4 Base Operations	AFI 65-503	CER / ANA
2.3.4 Program Support	AF Budget/Space Prgm	ANA
2.3.5 R&D	AF Budget/R&D	ANA / CER

Table 2-11 Air Force Data Sources
*ANA – analogy, ECE – engineering cost estimate, CER – cost estimating relationship
**Air Force Instruction 65-503 (USAF Cost & Planning Factors)

Air Force Instruction 65-503 contains the official planning factors for use in estimating resource requirements and costs associated with force structures, missions, and other activities.[8] This instruction addresses operating and support (O&S) cost estimates for Air Force weapon systems, primarily aircraft. The Air Force Budget, consisting of the budget titles listed in Table 2-12, provided the second major source of cost data.

Budget Title	Funds
Military Personnel	Pay and allowances, travel
Operations and Maintenance	Training and operation costs, civilian pay, contract services to maintain equipment and facilities, fuel, supplies, and repair parts.
Procurement	Acquisition of aircraft, ships, combat vehicles, satellites and their launch vehicles, weapons, and all capital equipment.
Research, Development, Test, and Evaluation	Modernization through basic and applied research, fabrication of technology-demonstration devices, and development and testing of prototypes and full-scale preproduction hardware

[8] Accessed through SAF/FMC web site.

Military Construction	New construction or major facility repair
Family Housing	The planning, design, and construction of new and replacement housing units; alteration and renovation of existing units; and operation and maintenance of government-owned units
Revolving and Management Funds	Requests for services, equipment, or material from a working capital fund

Table 2-12 Air Force Budget Categories

2.5 Costing Methodology

2.5.1 General

The cost of operating and maintaining a system over its useful life is driven primarily by policy, system design, operating rate, and subsystem reliability and maintainability. Therefore the costing methodology should be sensitive to changes in these factors.

To quote AFI 65-503, "Complexity is not a desirable trait in an O&S cost model. Often the cost, labor hours, and schedule required to set up and provide data for a complex model prohibits its effective and timely use in the decision process. The model should be structured so that it is useful in the early phases of the acquisition program and can evolve to accommodate more information as the program continues through the acquisition phases." (Atch A-54-1)

Taking the above into consideration, the general approach can be summarized in the following steps:

1. For most cost elements, both a Shuttle cost and aircraft cost are computed. A weighted average of these two costs are then found based upon a (user) specified percentage. That is

   Annual Recurring Cost (FY05 $M) = Percent Shuttle x Shuttle derived cost
   + (1 - Percent Shuttle) x aircraft derived cost

2. The Shuttle derived cost will be based upon the Access to Space cost study modified by a scaling factor as discussed in the next section.

3. Where the data permits, the aircraft derived cost with be determined parametrically in the form of a Cost Estimating Relationship (CER); otherwise, an analogy or engineering cost estimate as discussed in section 2.5.4 will be used.

4. The Annual Recurring Cost is then adjusted to the base year dollars and if discounting is selected, a present value at the base year is found over the life of the system.

5. All initial costs will be reported in base year dollars.

2.5.2 Scaling

When computing costs in the Shuttle mode, differences in scale between the Shuttle STS and the proposed system must be accounted for. This is accomplished by multiplying the Shuttle derived cost by

an appropriate factor prior to computing a weighted average of the Shuttle and aircraft derived costs. Table 2-13 lists the factor that is applied for each cost element.

Cost Element	Scaling Variable
2.3.1 Operations	
2.3.1.1 Refurbishment	SRM engine thrust, SRB empty weight
2.3.1.2 Organizational Maintenance	Total maintenance hours per mission
2.3.1.3 Processing Operations	SRB empty weight, ET volume
2.3.1.4 Integration Operations	SRB empty weight
2.3.1.5 Payload Operations	Average payload weight
2.3.1.6 Transfer	Not used
2.3.1.7 Launch Operations	Total launch weight including vehicle, SRB, ET, fuel and propellant weights, and payload.
2.3.1.8 Mission	(Crew size + passengers) x mission length (i.e. Crew-Hrs per Mission)
2.3.1.9 Landing/Recovery/Receiving	Vehicle dry weight and SRB empty weight
2.3.1.10 Non-nominal Operations	Wetted area (applied to cost of orbiter)
2.3.2 Logistics Support	
2.3.2.1 Depot Maintenance	LRU removals
2.3.2.2 Modifications	Vehicle wetted area, SRB and ET empty weight
2.3.2.3 Spares	LRU removals per mission, engine thrust, SRB and ET empty weight
2.3.2.4 Expendables	ET propellant volume
2.3.2.5 Consumables	Fuel weight
2.3.2.6 Inventory Management & Warehousing	LRU removals per mission
2.3.2.7 Training	Organizational + Depot Maintenance cost and launch operations cost
2.3.2.8 Documentation	Weighted subsystem count based on subsystem weights
2.3.2. 9 Transportation	Per mission number of vehicle off-site and non-mission landings or transports (e.g. OMDP) and shipments of ETs and SRBs
2.3.2.10 Support Equipment	CES 2.3.1.2 + CES 2.3.1.3 + CES 2.3.1.4 + CES 2.3.1.9 and dry weight of vehicle (carrier aircraft)
2.3.2.11 ILS Management	Logistics Support cost minus ILS management cost
2.3.3 System Support	
2.3.3.1 Support	Wetted area, Adj Operations cost (CES 2.3.1)*, & Logistics cost (CES 2.3.2)
2.3.3.2 Facility O&M	CES 2.3.1.2 + CES 2.3.1.3 + CES 2.3.1.4 + CES 2.3.1.5 + CES 2.3.1.6 + CES 2.3.2.1 + CES 2.3.2.6 + CES 2.3.2.7 + CES 2.3.2.10
2.3.3.3 Communications	Adj Operations cost* (CES 2.3.1) + Logistics cost (CES 2.3.2)
2.3.3.4 Base Operations	Adj Operations cost*(CES 2.3.1) + Logistics cost (CES 2.3.2)
2.3.4 Program Support	Adj Operations cost* (CES 2.3.1) + Logistics cost (CES 2.3.2)
2.3.5 R&D	Adj Operations cost* (CES 2.3.1) + Logistics cost (CES 2.3.2)

Table 2-13 Shuttle Scaling Variables
*Adj Operations cost excludes the cost of non-nominal operations

2.5.3 Reallocating Aircraft Costs

The operations cost elements shown in Table 2-14 reflect the distribution of costs among these cost elements for the Shuttle based upon 8 flights per year. Because the aircraft data is not available for several of these cost categories, it may be desirable to reallocate the aircraft costs to reflect the same distribution as the Shuttle. This would be particular useful when the percent shuttle factor is neither one (all Shuttle) nor

zero (all aircraft). For the aircraft data, the launch operations CES contains most of the non-pay operations expenses while the mission CES contains most of the operations personnel costs. Because of scaling the Shuttle costs, these percentages can change. Therefore the computed percentages for the proposed vehicle will be used to reallocate the aircraft costs.

Cost Element	Annual Cost (FY05 $M)	Percent
2.3.1.3 Processing Operations	$12.14	2.52%
2.3.1.4 Integration Operations	$6.10	1.27%
2.3.1.5 Payload Operations	$60.08	12.49%
2.3.1.7 Launch Operations	$97.25	20.22%
2.3.1.8 Mission	$305.42	63.50%
Sum	$480.99	100.00%

Table 2-14 Example Percents of Shuttle Mode Operations Costs

2.5.4 Cost Estimating Techniques

There are several approaches to establishing a cost estimate. The approach used for each cost element varies and is based upon the available data. The general costing methods used are:

Analogy – the use of historical rates and percentages from a similar, well-defined system. Most of the Shuttle data was utilized in this manner.

Engineering Cost Estimate (ECE) – a bottoms-up approach that requires complete cost data be available that corresponds to an accounting approach.

Cost Estimating Relationships (CER) – establish a functional relationship using regression analysis between a cost element and one or more "driver" variables based upon historical data.

All three of these general approaches may be found in the methodology that is presented in the following chapters.

2.5.5 Personnel Cost Data

Pay and allowances for civilian and military personnel are based on the standard composite rate which includes basic pay, additional variable payments for overtime, holiday pay, night differentials, cost-of-living allowances, and the government contribution to employee benefits, insurance, retirement, and the Federal Insurance Contribution Act. Salaries are expressed as an annual fully burdened average salary for a given labor category.

Overhead Costs

In those cases in which overhead cost data are not available or no cost estimating relationship exists, a fixed percent of the non-overhead costs will be used. The default value for this percent is based upon the OMB A-76 Circular. The A-76 Circular defines overhead in the following manner:

> "*Operations overhead* is defined as those costs that are not 100 percent attributable to the activity under study, but are generally associated with the recurring management or support of the activity. *General and*

administrative overhead includes salaries, equipment, space and other activities related to headquarters management, accounting, personnel, legal support, data processing management and similar common services performed outside the activity, but in support of the activity. These costs are affected by the conversion of work to or from in-house, contract or ISSA."

The default overhead percent allotted to an agency for cost comparison as stated in the A-76 Circular is 12 percent (.12) of the direct and indirect labor cost.

2.5.6 Inflation and Discounting Adjustments

Since various cost elements may have different historical years, an inflation adjustment is made to bring the costs to an initial 2005 base year. This adjustment is based upon an average fiscal year inflation rate, $f_{yr\,t}$, provided by the NASA New Start Index Inflation Calculator.[9] The calculation for year t is:

$$COST_{2005} = COST_{yr\,t}(1 + f_{yr\,t})^{2005-t}$$

A further calculation is then made to adjust the cost to the base year identified by the user (assuming it is different from 2005) where *f* is the average annual inflation factor to be used for the period from 2005 to the base year (provided by the user).[10] The final cost is then given by:

$$COST_{base\,yr} = COST_{2005}(1 + f)^{base\,yr-2005}$$

This cost is then applied to both nonrecurring and recurring (annual) costs over the life of the system in order to obtain constant dollars at the base year.

If then year dollars is to be used, a present value discount rate, *d*, is computed based upon the future inflation rate, *f*, and a return on investment rate (ROI), *i*. The costs are reflected in present value terms at the base year using the annuity factor (AF):

$$AF = \frac{(1+d)^{N-1}}{d(1+d)^N}$$

$$where \; \frac{1}{1+d} = \frac{1+f}{1+i}$$

And where N is the economic or design life of the vehicle.

2.5.7 Learning Curve Adjustments

Learning curves are generally based upon a constant percent reduction in labor or costs for each doubling of the production quantity. Annual cost adjustments can be made to the cost elements identified in Table 2-1 to account for learning over time and, in the case of maintenance activities, vehicle aging over time. It is

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[9] http://www1.jsc.nasa.gov/bu2/inflation/nasa/inflateNASA.html

[10] If the base year is before 2005, then the appropriate historical inflation rate is applied.

assumed that learning takes place up to and including a maturity year over which time certain costs will continue to decrease. Following the maturity year, aging or wear out begins to occur resulting in increased maintenance costs. As an example of the learning process consider: "A higher flight rate leads to lower operation costs due to process improvement and learning curve effects. In case of Space Shuttle operations, a 30 % increase of flights per year (from 6 to 8 launches/year) leads to a 22 % decrease in Cost per Flight."[11] In support of increased maintenance costs consider: "Historical experience in aircraft and virtually all transportation systems has shown that repair and refurbishment costs increase as vehicles age. Thus, we can expect that more components will need to be tested, replaced, or rebuilt as the reusable vehicles become older." [12]

Let Y_x = annual cost for year x,
K = cost of the first (base) year, and
b = percent change in annual cost per doubling the number of years of operation, then

$Y_x = K\,x^n \ \ where\ n = \dfrac{\log b}{\log 2}$ and the total cost over X years is given by $COST_X = \sum_{x=1}^{X} K\,x^n$

To allow for both learning and aging, two different learning curve percents may be used in the following way:

Let b_1 = learning percent, b_2 = aging percent, M = years to maturity, and N = system life (N > M),

$n1 = \dfrac{\log b_1}{\log 2};\ \ n2 = \dfrac{\log b_2}{\log 2}$, then

Total cost over system life = $K\sum_{i=1}^{M} i^{-n1} + K\,(M^{-n1})\sum_{i=1}^{N-M} i^{-n2}$

Annual average cost = Total cost over system life / N.

Either or both learning curve effects can be negated by setting the learning percent equal to 100. The implementation of the learning curve allows the user to apply it to the Shuttle computed values only, the aircraft computed values only, or both to the cost elements shown in Table 2-15.

Cost Element	Learning	Aging
2.3.1.1 Refurbishment	✓	✓
2.3.1.2 Org Maintenance	✓	✓
2.3.1.3 Processing Operations	✓	
2.3.1.4 Integration Operations	✓	
2.3.1.7 Launch Operations	✓	
2.3.2.1 Depot Maintenance	✓	✓

Table 2-15 Learning Curve Cost Element Impacts

[11] Goehlich, Robert A.and Udo Rücker, "Low-Cost Management Aspects For Developing, Producing, And Operating Future Space Transportation Systems," Technical University Berlin, Institute Of Aero- and Astronautics, Spacecraft Technology (circa 2003)
[12] Wertz, James R., Economic Model Of Reusable Vs. Expendable Launch Vehicles

If the option to discount to present value is selected, the discount rate is applied to the learning curve adjusted cost flows as shown in the following equation:

$$\text{Total cost over system life} = K\sum_{i=1}^{M}\frac{i^{-n1}}{(1+d)^{i}} + K\,(M^{-n1})\sum_{i=1}^{N-M}\frac{i^{-n2}}{(1+d)^{(M+i)}}$$

The annuity factor will not be applied in this case since there would no longer be equal annual payments.

3.0 OPERATIONS

3.1 Operations (CES 2.3.1)

Operations consist of those activities most directly associated with the on-line processing of the vehicle and support of its mission. Unless otherwise indicated, all costs are in FY 2005 dollars.

3.2 Refurbishment (CES 2.3.1.1)

3.2.1 Definition

Refurbishment consists of those tasks that are required to bring a flight element and associated support equipment and facilities back to a condition of readiness from a condition that exceeds normal wear and tear due to operations. Examples include the extensive replacement and rebuilding frequently associated with water landing such as the solid rocket booster (SRB) and repair and recondition of the launch pad and mobile launcher platform (MLP) following vehicle launch. For these items, a significant portion of their refurbishment cost is flight rate driven.

3.2.2 Shuttle Costing

Activity	**FY05 $M Annual**	
Solid Rocket Motor (SRM)[13]		FY05 $M per Flight per SRM
Sustaining Engineering	85.7	5.357
Touch & Support Manufacturing & Refurbishment Labor	246.9	15.434
Expendable/Reusable Hardware	17.3	1.084
Tooling Maintenance & Computer Support	25.5	1.594
Freight	9.9	0.622
Total SRM	385.3	24.091
Solid Rocket Booster (SRB)		FY05 $M per Flight per SRB
Touch & Support Labor	49.7	3.109
Expendable/Reusable Hardware	35.1	2.192
Sustaining Engineering & Management	58.9	3.683
Vendor Refurbishment of Reusable Hardware	23.9	1.491
Travel, Computer & Other ODC	18.8	1.172
KSC Support, Communications & Sys Analysis	7.5	0.470
Total SRB	193.9	12.1

[13] SRM and SRB costs were originally listed under Expendables (CES 2.3.2.4) and MLP and PAD maintenance were originally listed under Facility O&M costs (CES 2.3.3.2)

Mobile Launcher Platform (MLP)			FY05 $M per Flight
Maintenance		8.4	1.052
Launch Pads	Number of launches		FY05 $M per Launch
PAD A Maintenance	4	11.6	2.902
PAD B Maintenance	4	13.3	3.316
Total		742.6	92.825

Table 3-1 Shuttle Refurbishment Costs (Source: Access to Space Study)

SRM/SRB Data	Per SRB/SRM
Empty weight	87,543 kilograms (193,000 pounds)
Propellant weight	502,126 kilograms (1,107,000 pounds)
Thrust at lift-off	1,202,020 kilograms (2,650,000 pounds)

Table 3-2 SRM/SRB Data
Source: http://spaceflight.nasa.gov/shuttle/reference/basics/srb/index.html

Table 3-3 was obtained by determining for each cost activity in Table 3-1 whether it was an annual cost or a cost per flight.

Activity	FY05 $M Annual	FY05 $M per Flight per SRM
Solid Rocket Motor (SRM)		
Sustaining Engineering	85.7	
Touch & Support Manufacturing & Refurbishment Labor		15.434
Expendable/Reusable Hardware		1.084
Tooling Maintenance & Computer Support	25.5	
Freight		0.622
Total SRM	111.2	17.14
Solid Rocket Booster (SRB)		FY05 $M per Flight per SRB
Touch & Support Labor		3.109
Expendable/Reusable Hardware		2.192
Sustaining Engineering & Management	58.9	
Vendor Refurbishment of Reusable Hardware		1.491
Travel, Computer & Other ODC		1.172
KSC Support, Communications & Sys Analysis	7.5	
Total SRB	66.4	7.964
Mobile Launcher Platform (MLP)		FY05 $M per Flight
Maintenance		1.052
Launch Pads		FY05 $M per

		Launch
PAD Maintenance	Average	3.109

Table 3-3 Refurbishment Cost Basis

Using Table 3-3,

Refurbishment cost per flight = 17.14 x Number SRMs x 1000 lbs of thrust / 2650 + 7.964 x Number SRBs x empty weight in 1000 lbs./ 193 + (1.052 x MLP) + (3.109 x PAD)

where MLP = 1 if used, 0 otherwise; PAD = 1 if used, 0 otherwise

and Annual reoccurring cost (CES 2.3.11)

= 111.2 x SRM + 66.4 x SRB + Refurbishment cost per flight x nbr flights per yr

where SRM = 1 if used, 0 otherwise; SRB = 1 if used, 0 otherwise;

3.2.3 Aircraft Costing

The Prevail model [28] defines refurbishment as the repair or replacement of those subsystems that have deteriorated beyond normal wear and tear to include sustaining engineering for refurbishment items. Refurbishment costs are then computed as a fixed percent of the average production cost plus sustaining engineering cost. Engine refurbishment costs are computed separately.

To obtain an aircraft equivalent refurbishment cost, a fixed percent of the vehicle flyaway cost is assumed. The default is 2 percent. Vehicle flyaway cost is determined parametrically as derived in Paragraph 3.3.2.2 Modifications (CES 2.3.2.2).[14]

Annual reoccurring cost (CES 2.3.1.1) = Refurbishment Percent x vehicle flyaway cost x flight rate.

3.3 Organizational Maintenance (CES 2.3.1.2)

3.3.1 Definition

Organizational Maintenance includes all tasks required to return the reusable launch elements to a state of flight readiness. This includes those unscheduled tasks required due to component failures and those scheduled task that are planned as a part of the normal processing to ensure component operation (lubricating, servicing, periodic tasks). Also included are off-vehicle tasks required to support the shop work. Excluded are depot level repairs, depot rework, and depot engine and vehicle overhauls.

3.3.2 Shuttle Costing

Activity	FY05 $M	FY05 $M per Flight
ENG-Anomaly Resolution	28.4	3.6
ORB&GSE-Tile Spares & Maintenance	33.6	4.2

[14] The Orbiter Flyaway Unit Cost has been estimated at $: 63.00 million in 1988 unit dollars.

Orbiter Maintenance	79.1	9.9
Orbiter Shop Operations	11.3	1.4
Orbiter Tile Operations	22.6	2.8
Total	175.0	21.9

Table 3-4 Shuttle Organizational Maintenance Costs (Source: 1994 Access to Space Study)

Maintainability	
Maintenance actions per mission	1617.49
Maintenance hours per maintenance action (MA)	31.04
Unscheduled hours per mission	50,206.42
Scheduled hours per mission	79,567.35
Periodic inspection hours per mission	0.00
Total maintenance hours per mission	129,773.80
(weighted) Average crew size	1.7
On-vehicle MTTR per task	18.8 hours

Table 3-5 RMAT Shuttle Maintainability Parameters[15]

Annual reoccurring cost (CES 2.3.1.2) = $21.9M x number of flights per year x vehicle maintenance hrs / shuttle maintenance hrs (129,773.8)

3.3.3 Aircraft Costing

Air Force organizational maintenance costs consist of three distinct elements: direct labor maintenance personnel, maintenance overhead, and maintenance materiel. Personnel costs include the pay and allowances for personnel performing maintenance and support of assigned aircraft, support equipment, and unit-level training devices. It also includes both organizational (on-equipment) maintenance and intermediate (off-equipment) maintenance.

Material Cost

Aircraft	Average FY05$ per flying hr*	Aircraft	Average FY05$ per flying hr*
A-10	$503.03	E-4	$292.38
B-1	$1,902.42	F-117	$160.81
B-2	$760.19	F-15	$679.04
B-52	$726.31	F-16	$580.48
C-130	$681.29	F-22	$673.57
C-135	$309.84	T-37	$83.82
C-141	$750.44	T-38	$321.21
C-5	$1,439.31	T-43	$23.39

[15] Source: RMAT 2004 (V5.9.2) - Import of sts8-BM from RMAT2003, Version 4.1.0. STS RMAT2004 Benchmark Case; 20% serial work on tiles, main propulsion, RCS, OMS, APU and 10% serial work on separation.

E-3	$610.94	F-16	$580.48

Table 3-6 Flying Hour Consumable Supplies (FHCS)[16]

From the data provided in Table 3-6, the following regression equation was derived:

```
Material Cost (FY05$ per flying hour) = - 497 + 0.00270 x body weight + 183 x square
root(avionics weight) + 6.0 x number of control surfaces

11 cases used

Predictor        Coef        StDev         T        P
Constant       -496.5        865.3     -0.57    0.584
WGT BODY     0.002696     0.006122      0.44    0.673
sqravwgt        183.1        191.3      0.96    0.371
CTRL SUR         6.04        18.08      0.33    0.748

S = 338.3   R-Sq = 46.7% Average = 593.9

Alternate regression equation:

Material Cost (FY05$ per mission) = - 1541 + 0.077 Avionics Weight + 156 Number of
control surfaces + 0.80 square root(dry weight) + 182 log(number engines)

16 cases used

Predictor        Coef        StDev         T        P
Constant        -1541         1483     -1.04    0.321
AVCS WGT       0.0765       0.1616      0.47    0.645
CTRL SUR       155.71        87.25      1.78    0.102
sqr dyr         0.801        8.094      0.10    0.923
ln eng            182         1914      0.09    0.926

S = 2387        R-Sq = 59.4% Average = $2,455 per mission
```

Direct Labor Cost

Direct labor costs are determined from RMAT generated output which provides the required number of personnel by work center (WBS). This includes both the scheduled and unscheduled maintenance necessary to meet both a flying rate and vehicle turn-time goal. The number of personnel in each work center is then converted into a direct labor cost:

Direct Labor Cost = Avg technician annual salary (fully burdened) x Number of Personnel

Overhead Cost

From the MACO model [30], the regression equations in Table 3-7 are used to obtain total overhead hours per month:

Function	Equation (Y = hrs per month)
Chief of Maintenance	$Y_1 = 2125.6 + .5032$ x mission hours per month
Quality Control	$Y_2 = 3477.2 + .7469$ x missions per month
Maintenance Control	$Y_3 = 475.4$
Job Control	$Y_4 = 1082.7 + 1.143$ x mission hours per month

[16] Source: AFI 65-503, attachment 2-1. FHCS consists of supplies to be expended in general support within maintenance. The FHCS factors measure expendable supplies directly associated with the repair of flying mission assets at the base.

Plans & Schedules	$Y_5 = 532.8 + 1.0813$ x missions per month
Documentation	$Y_5 = 264.2 + 6.393$ x number of vehicles
Material Control	$Y_6 = 19.18$ x (missions per month)$^{0.4269}$
Supply Liaison	$Y_7 = 505.8 + 1.013$ x missions per month
Production Control	$Y_8 = 713.7 + .9658$ x missions per month
Total Overhead Hours	$Y = Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6 + Y_7 + Y_8$

Table 3-7 Maintenance Overhead Equations

Overhead Cost = Avg technician annual salary (fully burdened) x rounded[Y/ Avail hours per month]

Organizational Maintenance (CES 2.3.1.2) Cost
= Direct Labor Cost + Overhead Cost + Material Cost x missions per year

3.4 Processing Operations (CES 2.3.1.3)

3.4.1 Definition

Processing Operations consists of those functions required to receive and prepare launch elements for integration into a launch vehicle including the inspection, corrective tasks, and check out required prior to assembly. This activity includes the preparation of expendable or semi-expendable elements such as the ET and SRBs.

3.4.2 Shuttle Costing

Activity	FY05 $M per Flight
SRB Processing Operations	0.7653
SRB Shop Operations	0.2392
ET Processing Operations	0.4624
ET Shop Operations	0.0478

Table 3-8 Shuttle Processing Operations Costs (Source: 1994 Access to Space Study)

Cost per flight = (1.0045 x SRB empty weight in 1000 lbs / 193} x Nbr SRBs /2

+ (.5102 x volume of ET in 1000 gals / 526) x Nbr External Tanks

Annual reoccurring cost (CES 2.3.1.3) = Cost per flight x flight rate

3.4.3 Aircraft Costing

The aircraft equivalent consists of performing maintenance on components such as external fuel tanks or external pods. Some of this work would be done by flight line specialists assigned to the organizational level maintenance unit. It is assumed that this workload is accounted for within the Organizational Maintenance CES (2.3.1.2). Additional processing operations cost is accounted for under Launch Operations (CES 2.3.1.7). A portion of that cost can be re-allocated to this cost element.

3.5 Integration Operations (CES 2.3.1.4)

3.5.1 Definition

Integration Operations includes those functions required to assemble, stack, mate or integrate elements of the launch system. Also included is an integrated systems check prior to payload integration.

3.5.2 Shuttle Costing

Activity	FY05 $M per Flight
SRB Stacking	0.7494

Table 3-9 Shuttle Integration Costs (Source: 1994 Access to Space Study)

Cost per flight = 0.7494/2 x SRB empty weight in 1000 lbs / 193} x Nbr SRBs

Annual reoccurring cost (CES 2.3.1.4) = Cost per flight x flight rate

3.5.3 Aircraft Costing

The aircraft equivalent consists of installing external components such as fuel tanks and pods to the aircraft followed by a systems check. Much of this work would be done by flight line specialists assigned to the organizational level maintenance unit. It is assumed that this workload is partially accounted for within the Organizational Maintenance CES (2.3.1.2). Additional integration operations cost is also accounted for under Launch Operations (CES 2.3.1.7). A portion of that cost can be re-allocated to this cost element.

The basic cost computed in the aircraft mode is based upon estimated maintenance hours during PAD and integration time. Therefore

Annual reoccurring cost (CES 2.3.1.4) = Annual maintenance salary x maintenance crew size x round up [flight rate x (PAD + Integration hours per flight) / Available direct hours per person per year]

3.6 Payload Operations (CES 2.3.1.5)

3.6.1 Definition

Payload Operations includes both the Payload Preparations and the Payload Integration tasks for installing (and removing) the payload in the launch vehicle. Also includes both payload and payload/vehicle interface checks.

3.6.2 Shuttle Costing

Activity	FY05 $M per Flight
Payload Preparation & Transportation	4.736*
Payload Integration & Launch Operations	1.818
Total	$6.554

Table 3-10 Shuttle Payload Operations Costs[17] (Source: 1994 Access to Space Study)

Date	Mission	Vehicle	Launch Site	Landing Site	Payload (kg)	Payload (lbs)
18-Oct-93	STS-58	*Columbia*	LC-39B	Edwards AFB	11,803	26,021
2-Dec-93	STS-61	*Endeavour*	LC-39B	Kennedy	10,949	24,138
3-Feb-94	STS-60	*Discovery*	LC-39A	Kennedy	10,231	22,555
4-Mar-94	STS-62	*Columbia*	LC-39B	Kennedy	8,759	19,310
9-Apr-94	STS-59	*Endeavour*	LC-39A	Kennedy	12,490	27,535
8-Jul-94	STS-65	*Columbia*	LC-39A	Kennedy	10,811	23,834
9-Sep-94	STS-64	*Discovery*	LC-39B	Edwards AFB	9,260	20,415
30-Sep-94	STS-68	*Endeavour*	LC-39A	Edwards AFB	12,510	27,580
				Average	10,852	23,923

Table 3-11 FY 94 Shuttle Payloads (Source: http://en.wikipedia.org/wiki/List_of_space_shuttle_missions)

Payload cost is based upon an average shuttle payload cost per mission of $7.51M averaged over 8 flights having an average payload of 23,923 pounds. The orbiter's payload bay measures 60 feet long, 17 feet wide, and 13 feet deep or 13,260 cubic feet.

Annual reoccurring cost (CES 2.3.1.5) = Annual Flight Rate x $6.554 x average payload in pounds / 23,923

3.6.3 Aircraft Costing

Airlift aircraft payloads generally consist of palletized cargo or passengers while fighter and bomber payloads consist of munitions. Although each have payload assembly and loading activities, the times and costs associated with these activities would not be comparable to the types of mission payloads encountered in space operations. Therefore aircraft data is assumed not to be relevant.

The Hypervelocity Aerospace Vehicle cost study developed the following CERs for payload deployment and retrieval. These have been adjusted for FY05 $M per mission.

Maintenance personnel cost = 0.039575 x Payload Volume$^{.3562}$ (volume in cu. ft.)
Maintenance material = .00002815 x payload wgt$^{.79221}$ x Nbr Exits (powered)$^{.024399}$ (weight in lb.)
Depot personnel = .000647 x Payload Volume$^{.55731}$ x (flight crew + mission crew)$^{.022272}$
Depot material = 1.78 x 10^{-5} x Payload Volume$^{.44168}$ x payload wgt$^{.4}$
Replenishment spares = 1.96 x 10^{-5} x Payload Volume$^{.20537}$ x payload wgt$^{.70128}$
Data = .01 x UPC (unit flyaway cost)
Initial support equipment = .02 x UPC (unit flyaway cost)
Replacement support equipment =.004 x UPC (unit flyaway cost)
Initial spares = .025 x UPC (unit flyaway cost)

Annual reoccurring cost (CES 2.3.1.5) = (Maintenance personnel cost + Maintenance material + Replenishment spares) x Annual Flight Rate

---

17 GSE sustaining engineering moved to support equipment ($.957M)

3.7 Transfer (CES 2.3.1.6)

Definition: Transfer consists of those functions required to transport the integrated launch system to the launch site. This activity does not include any integration test required at the launch site.

This activity is included as part of Launch Operations (CES 2.3.1.7) or in the case of aircraft is considered to have a negligible cost.

3.8 Launch Operations (CES 2.3.1.7)

3.8.1 Definition

Launch Operations consists of all tasks required to perform pre-launch testing and servicing and includes launch countdown through launch. These tasks include the interface tests between the vehicle and the launch site (if required) and propellant loading. This activity includes positioning the vehicle on the launch Pad and all subsequent launch Pad processing.

3.8.2 Shuttle Costing

Launch Operations Activities	FY05 $M Annual	FY05 $M per launch
Integrated Vehicle Servicing	15.817	1.977
Integrated Vehicle Test and Launch Operations	23.598	2.950
Launch Operations Support	13.011	1.626
Launch Support Services	44.644	5.581
Total	97.07	12.134

Table 3-12 Shuttle Launch Operations Costs (Source: 1994 Access to Space Study)

From Table 3-12, costs are identified as either an annual cost or a cost per flight in Table 3-13.

Launch Operations Activity	FY05 $M Annual	FY05 $M per launch
Integrated Vehicle Servicing		1.977
Integrated Vehicle Test and Launch Operations		2.950
Launch Operations Support	13.011	
Launch Support Services	44.644	
Total	57.655	4.927

Table 3-13 Shuttle Launch Costs

Launch weight (lbs.) = empty weights of vehicle + SRB + ET + all fuel weight and propellant weights + payload weight
Annual reoccurring cost (CES 2.3.1.7) = (57.655 + 4.93 x flight rate) x launch weight / 3,159,923

3.8.3 Aircraft Costing

For aircraft in general this activity would consist of refueling and preflight activity performed by the maintenance organization and accounted for within Organizational Maintenance (CES 2.3.1.2). The cost data provided below is in support of Air Force launch operations on unmanned and non-reusable vehicles and provides basic O&M costing but does not include military personnel cost. These costs are accounted for in the mission cost element (CES 2.3.18).

Launch Facility Costs (Budget activity group: Space Operations)

"Description of cost category: The spacelift ranges are composed of the Western Range (WR) headquartered at the 30th Space Wing, Vandenberg AFB, CA and the Eastern Range (ER) headquartered at the 45th Space Wing, Patrick AFB, FL. The spacelift ranges provide tracking, telemetry, communications, range safety, weather and other support for DoD, civil and commercial space launches, intercontinental and sea-launched ballistic missile test and evaluations (T&E) and aeronautical T&E. The spacelift ranges consist of range operations control centers, hardware and software required to provide command and control of day-to-day range and launch operations. They consist of instrumentation that provides range safety and user metric data through the use of launch vehicle telemetry, weather instruments, metrics, optics and uplink capabilities. They also provide a conduit for sending all voice, video, and data to and from remote and local instrumentation sites. The spacelift ranges are responsible for infrastructure maintenance functions, to include heating and air conditioning, fire protection/detection, and corrosion control. Also, spacelift range funding pays for contractor payload/vehicle operations necessary to ensure successful space launches, contract range activities necessary to support launch of operational space vehicles and payloads, and contract activities necessary to operate and maintain range systems. Operations and maintenance of the launch pads is not included in this funding category." [18]

Fiscal Year	2003	2004	2005
Atlas	4	8	1
Delta	9	8	15
Titan	3	2	2
Pegasus.	4	0	1
Taurus.	0	0	0
Space Shuttle	3	1*	5*
ICBMs	4	5	6
Other	18	2	9
Total.	45	26	39

Table 3-14 AF Launch Activity

FY05 $ in thousands	FY2003 Actuals	FY 2004 Estimate	FY 2005 Estimate
Spacelift Range System (Space)	$183,078	$218,259	$252,953
Western Spacelift Range Operations	$81,673	$94,661	$89,118
Total	$264,751	$312,921	$342,071
Number of launches	45	26	39
Cost per launch	$5,883.36	$12,035.41	$8,771.05

[18] Source: Department of the Air Force, Fiscal Year (FY) 2005 Budget Estimates, February 2004, Operation and Maintenance, Active Forces Vol I. Includes launches by DOD, NASA and commercial.

Table 3-14 AF Launch Costs

Since the available Air Force data did not separate fixed costs from variable (flight rate) costs, first a cost per flight was determined as a function of the flight rate as displayed in Figure 3-1.

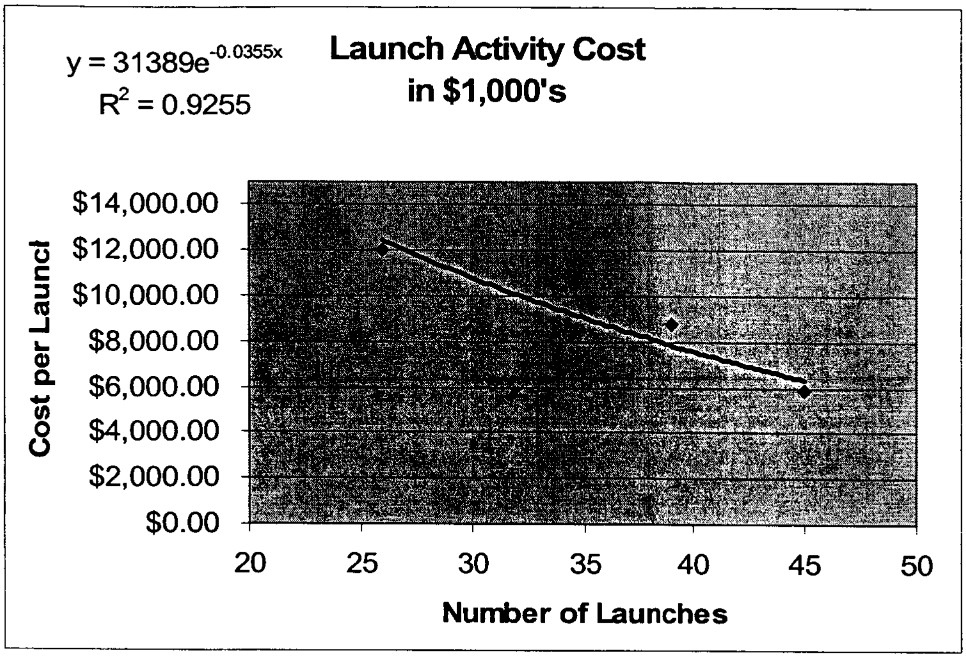

Figure 3-1 Number launches versus Launch Cost

Next, the following total costs were computed based upon the estimated cost per launch at each of the launch rates shown.

Nbr Launch	1	2	3	4	5	10	15	20
Cost/launch	$30,294	$29,238	$28,218	$27,234	$26,284	$20,501	$18,430	$15,432
Total	$30,294	$58,475	$84,654	$108,935	$131,420	$246,008	$276,444	$308,644

Table 3-15 Estimated Launch Operations Costs (2005 yr 1000's dollars)

Launch schedule	FY 2003	FY 2004	FY 2005
Atlas IIA	0	2	0
Atlas III	0	0	1
Delta II	2	4	4
Titan II	1	1	0
Titan IV	2	1	2
EELV (Atlas V)	0	0	0
EELV (Delta IV)	2	1	6
Total	7	9	13

Table 3-16 AF Vehicle Launch Activity

The Launch Vehicle Costs (Budget activity group: Space Operations) found in Table 3-17 provides launch and operational support to the AF launch vehicles. Support includes fuel, overtime, pad refurbishment, and maintenance. The average of these costs is used as a fixed annual cost in support of the launch facility.

$ In Thousands FY05	FY 2003	FY 2004	FY 2005	
Program Elements:	Actuals	Estimate	Estimate	average
1. Evolved Expendable Launch Veh(Space)	$50,957	$22,280	$24,280	$32,506
2. Medium Launch Vehicles (Space)	$46,562	$20,356	$17,235	$28,051
4. Titan Space Launch Vehicles (Space)	$49,893	$21,775	$59,146	$43,605
Total	$147,412	$64,411	$100,661	$104,161
Launches	7	9	13	10
Cost per launch	$21,059	$7,157	$7,743	$11,986

Table 3-17 Launch Budget Program[19]

Annual costs are computed as the sum of a fixed cost and a cost driven by the flight rate.

Annual reoccurring cost (CES 2.3.1.7) = (12.0 + 31.389 x Exp[-0.0355 x flight rate])x flight rate

3.9 Mission (CES 2.3.1.8)

3.9.1 Definition

Mission Operations include preflight planning, in-flight support, and post-flight analysis. These functions consist of:

- Planning:
  - Mission Planning - the tasks required to plan and coordinate different payload objectives to identify missions that can best satisfy differing requirements.
  - Flight Planning - the tasks required to develop flight profile trajectory and mission designs.
  - Flight Data Development- the tasks required to document the flight and mission plans.
  - Crew Activity Planning - the tasks required to plan and schedule crew activities.
  - Payload Analysis & Integration - the tasks required to assure integration into the cargo and mission.
- Flight Simulation - the tasks required to configure and maintain the simulation facilities to support the required training.
- Training -includes the task of training both flight crews and those supporting mission operations and includes the cost of specialized training equipment such as aircraft used primarily for training.
- Real-time support includes the task required to manage, monitor, and control the flight during the active mission phase (i.e. from liftoff through landing).
- Postflight - The tasks required for postflight analysis

[19] Source: Department of the Air Force, Fiscal Year (FY) 2005 Budget Estimates, February 2004, Operation and Maintenance, Active Forces Vol I.

3.9.2 Shuttle Costing

Activity	FY05 $M Annual	FY05 $M per launch
Mission Planning	19.5	2.4
Flight Planning	37.0	4.6
Flight Data Development	125.1	15.6
Flight Simulation	10.2	1.3
Crew Activity Planning	5.5	0.7
Flight Crew Operations	1.0	0.1
Training	94.3	11.8
Real Time Support	12.8	1.6
Total Mission	305.4	38.2

Table 3-18 Shuttle Mission Costs (Source: 1994 Access to Space Study)

Date	Mission	crew	Duration (days)
18-Oct-93	STS-58	7	14
2-Dec-93	STS-61	7	10.83
3-Feb-94	STS-60	6	7.25
4-Mar-94	STS-62	5	14
9-Apr-94	STS-59	6	11.25
8-Jul-94	STS-65	8	14.75
9-Sep-94	STS-64	6	10.95
30-Sep-94	STS-68	6	11.25
Average		6	12

Table 3-19 FY94 Mission data

Costs are identified as either an annual cost or a cost per flight in Table 3-20.

Activity	FY05 $M Annual	FY05 $M per launch
Mission Planning		2.4
Flight Planning		4.6
Flight Data Development		15.6
Flight Simulation		1.3
Crew Activity Planning		0.7
Flight Crew Operations		0.1
Training	94.3	
Real Time Support		1.6
Total Mission	94.3	26.3

Table 3-20 Shuttle Annual versus Flight Mission Costs

Annual reoccurring cost (CES 2.3.1.8)
= (94.3 + 26.3 x flight rate) x [(flight crew size + mission crew size) x mission length (hrs)] / (6 x 12 x 24)

If crew size + mission crew = 0 then Annual reoccurring cost (CES 2.3.1.8) = (2.4 + 4.6 + 15.6) x

mission length (hrs)] / (12 x 24).

3.9.3 Aircraft Costing

Aircraft costing of this cost element is comprised of vehicle crew personnel costs, training costs, training aircraft and simulator costs, and mission support costs. It is assumed that aircraft used in aircrew training are not necessarily the vehicles that comprise the STS and that aircrew training is a continuous on-going activity

Reimbursement Rates FY05	
Aircraft	Public Rate per flying hour*
T-38A	$1,478
C-17A	$5,795
F-15A	$11,616
KC-10A	$9,695
Average	$7,146

Table 3-21 Aircraft Reimbursement Rates (Source: AFI 65-503 Attachment A15-1)
*Rates reflect the cost of operating the aircraft for one hour.[20]

Initial Aircrew Training

	FY 05$	FY 05$	
VEHICLES	Personnel	O&M Costs	Total*
C017	$294,687	$573,827	$868,515
C130	$268,171	$421,962	$690,133
C135	$278,562	$467,905	$746,468
F015	$1,196,141	$3,123,398	$4,319,539
F016	$1,282,049	$1,844,085	$3,126,134
T001	$136,797	$168,920	$305,717
T037	$127,628	$120,743	$248,371
T038	$165,460	$287,784	$453,244
Average	$468,687	$876,078	$1,344,765

Table 3-22 Representative Officer Aircrew Training Costs[21] (Source: AFI 65-503 Table A34-2, October-03)

Unit mission personnel consist of aircrews, aircraft maintenance, and other unit personnel. Flight and mission crews are accounted for by the crew ratio and maintenance is accounted for within the organizational maintenance cost element (CES 2.3.1.2). The additional personnel listed in Table 3-23 are required for unit (squadron) command, flying supervision, operations control, planning, scheduling, flight safety and security, aircrew quality control, mission equipment personnel, and unit administration.

20 The elements, which comprise these reimbursement rates, are logistics costs (fuel, depot maintenance, depot level reparables and consumables), CLS costs, and personnel costs for (training) aircrew.

21 Includes instructor costs, school overhead costs, dormitory support (if applicable), maintenance (aircraft/training equipment), real property maintenance support, medical, other Base Operating Support (BOS) costs, i.e., comptroller, transportation, grounds maintenance, custodial; student costs and flying related costs, i.e., fuel, depot level reparables, CLS, etc.

		Squadron Staff			Security	Base Operating Support			Sq Size
MD	MDS	OFF	ENL	CIV	ENL	OFF	ENL	CIV	PAI
A010	A010	7	23	0	20	0	24	8	12
B001	B001B	6	22	0	88	1	56	18	12
B002	no data								
B052	B052H	6	23	0	88	1	57	18	12
C005	C005A/B	2	10	1	34	1	58	18	16
C009	AF reserve								
C010	KC010	3	20	1	34	0	26	8	12
C017	C17	8	9	4	11	0	18	6	8
C130	C130E/H	14	17	7	42	0	36	12	10
C135	KC-135R	4	27	0	21	0	37	12	15
C141	not active								
E003	E003	9	27	3		0	37	12	5
E004	E004B	3	19	0	51	0	26	8	3
F004	not active								
F015	F015C/D	14	20	4	29	1	45	14	24
F016	F016C/D	10	17	5	22	1	43	14	18
F117	F117A	6	21	0	20	0	34	11	18
T001	T001A	1	2	1	0	0	0	0	37
T037	T037B	1	2	1	0	0	0	0	39
T038	T038B	2	2	1	0	0	0	0	20
T043	Contract out								
U002	no data								

Table 3-23 Typical aircraft squadron strengths by category[22] (Source: AFI 65-503 Attachment 42-1)

Officer training costs for selected unit level skills other than aircrews is given in Table 3-24 and enlisted training costs for relevant skills are given in Table 3-25.

Officer Training

Specialty	Course Length (Weeks)	Total FY05$
Airfield Operations	15.2	$33,780
Space & Missile Operations	20.1	$44,663
Weather	12.4	$24,065
Security Forces	12.0	$22,945
EOD Officer	27.2	$69,093
Communications & Information	12.8	$24,469
Services Management	6.0	$13,576
Public Affairs	8.6	$17,322
Personnel	5.0	$11,594
Manpower	7.0	$14,771
Contracting	5.0	$11,564

22 Excluding aircrews and maintenance

Financial Management	12.2	$23,300
Average	12.0	$25,929

Table 3-24 Variable Cost by Officer Air Force Specialty[23] (Source: AFI 65-503 Attachment A18-1B, Mar-03)

Enlisted Training

AFSC Title	(Weeks)	Total FY05$
Flight Engineer Apprentice (Perform Qual)	13.3	$27,099
Aircraft Loadmaster Apprentice	11.7	$23,147
Airfield Management Apprentice	5.9	$6,946
Operations Resource Management Apprentice	5.5	$6,698
Air Traffic Control Apprentice	3.8	$2,046
Command & Control Apprentice	6.0	$5,478
Space Systems Operations Apprentice	13.3	$15,659
Safety Apprentice	7.0	$10,769
Survival Training	40.3	$70,579
Aircrew Life Support Apprentice	6.5	$7,238
Pararescue	97.5	$150,581
Weather Apprentice	19.9	$22,284
Survival Equipment Apprentice	13.4	$14,711
Missile & Space Facilities Apprentice	20.9	$23,404
Air Transportation Apprentice	5.8	$6,688
Information Management Apprentice	7.5	$7,761
Comm-Computer Systems Operator Apprentice	12.9	$13,213
Radio Comm System Apprentice	6.4	$7,333
Environmental Apprentice	6.7	$7,167
Engineering Apprentice	12.8	$16,087
Explosive Ordnance Disposal (EOD)	32.8	$55,422
Readiness	10.6	$16,136
Services Apprentice	6.3	$7,491
Public Affairs Apprentice	12.0	$20,476
Security Forces Apprentice	11.1	$11,697
Personnel Apprentice	5.8	$6,133
Education and Training Journeyman	7.4	$11,477
Manpower Management Journeyman	7.8	$16,541
Visual Information Apprentice	14.7	$23,363
Contracting Apprentice	8.0	$11,343
Financial Management Apprentice	11.7	$11,245
Dormitory Manager**	0.0	$0
Scientific Measurements Technician	27.0	$37,522
average	14.3	$20,416

Table 3-25 Initial Enlisted Skill Training[24]. (Source: AFI 65-503 Attachment A18-1A, Mar-03)

[23] Initial Skill Training – Officer acquisition costs are not included in this table. Course length is the length adjusted for training time expended on attrited students

[24] Airmen acquisition costs including basic military training (BMT) have been subtracted and costs adjusted from

Mission costs include the annual cost of pay and allowances for the full complement of flight crews required to operate the vehicle(s). The number of flight and mission crews necessary to meet mission readiness, training, and administrative requirements such as leave, sickness, temporary duty (TDY), and so forth are accounted for by the crew ratio (number of crews per vehicle). Generally flightcrew and mission crew training is assumed to be a continuous on-going process over the course of the year.

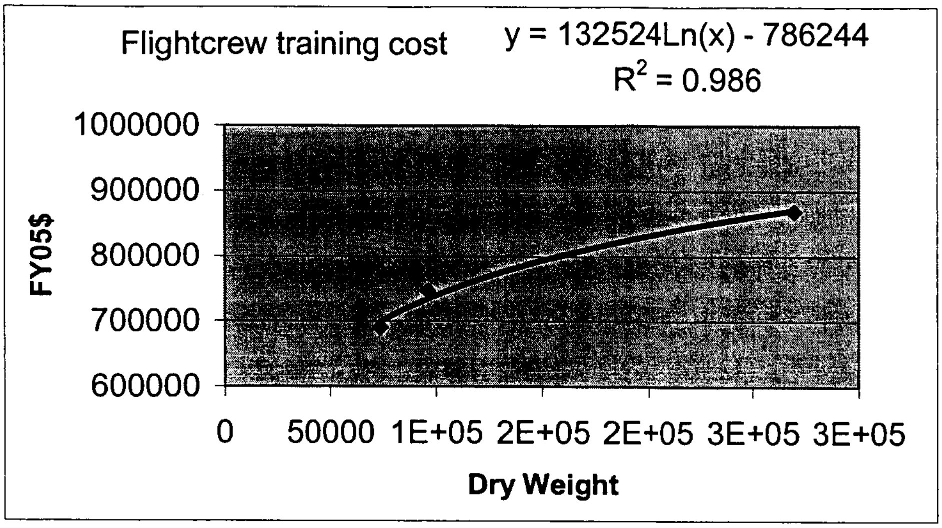

Figure 3-2 Crew Training Cost (Source: Table 2-22 and AFI 503 Table A34-2)

From Figure 3-2, the Initial flight training cost = Flight crew size x crew ratio x [132,524 ln(dry weight) – 786,244] (excludes personnel cost)

Initial non-rated officer training = $26,000 x number of assigned officers
Initial enlisted & civilian training = $20,416 x number of enlisted + civilians
Initial security training = $11,697 x number of security personnel

Flight crew cost = Crew ratio x flight crew size x annual cost per crew member
Mission crew cost = Crew ratio x mission crew size x annual cost per crew member
Recurring training cost = turnover rate x (Initial flight training cost + Initial non-rated officer training + Initial enlisted & civilian training + Initial security training)
Flight crew flight training = $7,146[25] / hour x flying hours per mission x flight rate x flight crew size
Mission crew flight training = $7,146 / hour x flying hours per mission x flight rate x mission crew size

The costs incurred to provide, operate, and maintain on-site or centralized training devices or simulators for a system or related equipment are estimated. This includes the labor, material, and overhead costs of simulator operations by government or contract personnel. Since simulator requirements are a function of the mission rate, an hourly simulator cost is utilized. Flight simulator cost is estimated to be $2,011,750 per year per based upon a $8.047 million (FY05$) contract awarded by the U.S. Air Force to operate and maintain the Air Force Research Laboratory's four flight simulation facilities at Wright-

[25] Average aircraft reimbursement rate per flying hour

Patterson Air Force Base, Ohio.[26]

Flight simulator cost per hour = $2,011,750 / (8 x 252) = $998

Simulator cost = $998 x (flight crew size x simulator hours per mission + mission crew size x simulator hours per mission) x flight rate

Operational Unit Personnel (aircraft squadron)

Officers: Squadron staff average = 6; base operating support average = 1

Enlisted excluding security

```
The regression equation is
Enl-Sec = 7.4 +0.000773 eng thrust + 0.00175 AVCS WGT + 4.81 ENGINES

13 cases used 9 cases contain missing values

Predictor        Coef        StDev          T        P
Constant         7.40        15.14       0.49    0.637
eng thru    0.0007729    0.0004119       1.88    0.093
AVCS WGT     0.001746     0.001386       1.26    0.240
ENGINES         4.805        4.143       1.16    0.276

S = 22.81       R-Sq = 53.3% Average = 47

The regression equation is
Number Security Personnel (ENL) = 6.21 + 2.56 CREWSIZE + 0.00906 AVCS WGT

11 cases used 11 cases contain missing values

Predictor        Coef        StDev          T        P
Constant        6.205        5.436       1.14    0.287
CREWSIZE        2.561        1.634       1.57    0.156
AVCS WGT     0.009064     0.001268       7.15    0.000

S = 8.951       R-Sq = 90.9% Average = 38
```

Civilian personnel:

```
The regression equation is
CIV = 4.18 +0.000244 eng thrust +0.000501 AVCS WGT

13 cases used 9 cases contain missing values

Predictor        Coef        StDev          T        P
Constant        4.178        2.868       1.46    0.176
eng thru   0.00024396   0.00009866       2.47    0.033
AVCS WGT    0.0005010    0.0003083       1.63    0.135
```

[26] At the Air Force Research Laboratory, Raytheon Systems Company will maintain, support and operate four facilities: the Crew Station Evaluation Facility, Vehicle/Pilot Integration Laboratory, Engineering Flight Simulation Facility, and Simulation and Analysis Facility. [reference: http://www.link.com/pr072198.html]

```
S = 5.575        R-Sq = 48.5% Average = 12
```

Total mission personnel cost = 7 x average officer grade pay + (number security + other enlisted personnel) x average technician pay + number civilians x average technician pay + flight crew cost + mission crew cost

Annual reoccurring cost (CES 2.3.1.8) = Total mission personnel cost + recurring initial training cost + flight crew flight training + mission crew flight training + simulator cost

Reallocation of operating costs

Once mission costing (CES 2.3.1.8) has been completed, the launch operations cost computed above for aircraft costing in cost elements 2.3.1.3 – 2.3.1.8 may be reallocated to conform to the computed shuttle percentages. Typical percentages are shown in Table 3-26.

Cost Element	Annual Cost	Percent
2.3.1.3 Processing Operations	\$12.14	2.88%
2.3.1.4 Integration Operations	\$6.02	1.43%
2.3.1.7 Launch Operations	\$97.25	23.11%
2.3.1.8 Mission	\$305.42	72.58%
Sum	\$420.83	

Table 3-26 Representative Redistribution of Operational Costs

Alternate:

The following CERs are from the Hypervelocity Cost Model [4] adjusted for FY 2005 costs. These are provided for information only and are not included at this time in the costing model.

Aircrew support cost = 0.39615 x [(Crew size x crew ratio) $^{1.6422}$] x nbr of vehicles$^{0.89681}$
Command staff support cost = 0.39615 x utilization rate $^{0.50621}$ x nbr of vehicles $^{0.89225}$
where utilization rate = missions per year x hours per mission / nbr of vehicles
Administrative staff cost = .2 x (Aircrew support cost + Command staff support cost)

3.10 Landing/Recovery/Receiving (CES 2.3.1.9)

3.10.1 Definition

Landing/Recovery/Receiving Operation includes all functions required to retrieve or recover a vehicle from the return location after a mission, or to receive those expendable elements from the manufacturing site. Specialized equipment (such as 747's, retrieval ships, and barges) required for this task is accounted for under Support Equipment. These costs apply only to reusable vehicles and their components. This is the cost of actual recovery plus return to the launch site or wherever the equipment is checked-out and refurbished. It will depend strongly on whether the vehicle or component is flown back from space to the launch or recovery site (such as the Orbiter), recovered after landing in the water (Shuttle Solid Rocket Boosters), or on land (Soviet and Russian manned capsules).

3.10.2 Shuttle Costing

Activity	FY05 $M per Flight
Orbiter Landing Operations	2.009
SRB Retrieval Ops and Disassembly Operations	0.638

Table 3-27 Shuttle Recovery Costs (Source: 1994 Access to Space Study)

Cost per flight = 2.009 x (vehicle dry weight / 171,919)
+ .638 x (Nbr SRBs / 2) x (SRB empty weight / 193,000)

Annual reoccurring cost (CES 2.3.1.9) = Cost per flight x flight rate

3.10.3 Aircraft Costing

Aircraft recovery costs are accounted for within the Organizational Maintenance cost element.

3.11 Non-nominal Operations (CES 2.3.1.10)

3.11.1 Definition

Non-Nominal Operations are all tasks required to return the system to nominal operations after an event occurs which does not match the planned scenario. This includes those tasks required to support a launch scrub or extended hold, a rollback to processing facilities, and the tasks required for return from a contingency return site.

A non-nominal event may be a ground abort that results in a rollback with subsequent additional launch preparation costs. An air abort that results in the early termination of the mission along with a safe return of the vehicle and crew may incur an additional cost resulting from incomplete delivery of the payload. However, for a catastrophic event that results in the loss of the vehicle, costs incurred may include a replacement spacecraft, the "opportunity cost" associated with not having the payload available until some later time, and a return to flight cost.

3.11.2 Shuttle and Aircraft Costing

An annual reoccurring training cost is computed for non-nominal recovery operations. An additional expected cost is computed based upon the probability of both a ground and air abort. Both abort rates are computed by RMAT.

Specialty	Course Length (Weeks)	Total FY05$
Para rescue	61.4	$127,102

Table 3-28 Para rescue Training Cost (Source: AFI 65-503 Attachment A18-1B, Mar-03)

Expected cost per flight = Probability of ground abort x cost of ground abort + probability of mission abort x cost of mission abort

A default ground abort cost is based upon incurring the integration and processing costs a second time as well as 50 percent of the payload and launch costs. That is,

Cost of ground abort = Processing Operations (CES 2.3.1.3) + Integration Operations (CES 2.3.1.4) + .5 x Payload Operations (CES 2.3.1.5) + .5 x Launch Operations (CES 2.3.1.7)

Default mission (air) abort costs include the sum of all operational costs with the exception of non-nominal costs and 50 percent of the mission cost. In addition, ten percent of the unit flyaway cost is added. A "return to flight" cost is not included.

Annual reoccurring cost (CES 2.3.1.10) = Training cost (5 x $127,102) + Expected cost per flight x flight rate

4.0 LOGISTICS SUPPORT

4.1 Logistics Support

Logistics support is those functions and secondary levels of support needed to sustain the operational activity and on-line maintenance activity.

4.2 Depot Maintenance (CES 2.3.2.1)

4.2.1 Definition

Depot Maintenance is those tasks required to repair and overhaul vehicle, engines, and components beyond the normal installation (base) level maintenance. This includes major vehicle or engine rework. Costs consist of personnel, materiel, and contractual services required to perform maintenance or modification of aircraft, components, and support equipment maintenance at a centralized repair depot or contractor repair facilities. Both common and peculiar support equipment and training equipment returned to a centralized facility are included.

4.2.2 Shuttle Costing

Activity	FY05 $M Annual	FY05 $M per Flight
ENG-Hardware Refurbishment	26.9	3.4
ORB&GSE-Overhaul & Repair	82.4	10.3
Total Depot	109.3	13.7

Table 4-1 Shuttle Depot Maintenance Cost (Source: 1994 Access to Space Study)

Cost per flight = 13.7 x (LRU removals / Shuttle LRU removals = 350) x depot overhauls per yr / (one Shuttle OMDP) x engine overhauls per yr / (3 Shuttle engine overhauls) x (thrust per engine / Shuttle thrust per engine)

Annual reoccurring cost (CES 2.3.2.1) = Cost per flight x flight rate

4.2.3 Aircraft Costing

Vehicle	FY05$ per mission hour*	Vehicle	FY05$ per mission hour*
A010	2225.4	E003	2589.6
B001	14865.7	E004	5138.7
B002	7458.9	F015	8036.8
B052	4179.1	F016	3153.8
C005	4213.3	F117	114.2
C017	123.8	T037	137.6
C130	2030.9	T038	518.6
C135	849.2	T043	156.0

C141	1993.9		

Table 4-2 Depot Level Reparables (DLR)[27] (Source: AFI 65-503, Attachment 2-1)

Vehicle	FY05$ per flying hr*	FY05$ per vehicle*
A010	40.77553	139502.3
B001	356.7859	686428.5
B052	1254.867	1367405
C005	1833.879	1300468
C010		220.1879
C017		4663.701
C130	181.4511	199429
C135	705.4166	687584.5
C141	750.2697	732249
E003	957.2055	1255157
F015	70.33779	231671.3
F016	143.7337	61887.06
T037		2555.606
T038		21285.84
T043		345.5726

Table 4-3 Aircraft Depot Maintenance Cost[28] (Source: AFI 65-503, Attachment 2-1)

Depot Level repair (FY05$ per flying hour)

```
The regression equation is
DLR = 1194 + 42.2 BTU COOL + 1.19 AVCS WGT - 0.393 ENG WGT

8 cases used 14 cases contain missing values

Predictor          Coef         StDev          T         P
Constant         1194.2         911.3       1.31     0.260
BTU COOL          42.19         10.51       4.01     0.016
AVCS WGT         1.1949        0.4108       2.91     0.044
ENG WGT         -0.3932        0.1043      -3.77     0.020

S = 1271          R-Sq = 81.3% Average= $3,400
```

Depot Level repair (FY05$ per mission) (not used)

27 Included are repair costs associated with vehicle and engine component equipment repair on items sent to a depot as a "not repairable this station" (NRTS) action including management costs, transportation, depreciation, and replenishment spare buys.

28 Depot Maintenance is the cost to inspect, repair, overhaul, or perform aircraft maintenance not performed at base level. It excludes costs of repairing base-generated Depot Level Reparables (DLR). This maintenance can be either organic or contract. Depot maintenance costs per flying hour are those costs associated with repair effort during engine overhaul. Depot maintenance costs per aircraft are those costs associated with repair effort during aircraft overhaul

```
The regression equation is
DLR per msn = - 5287 + 2.61 Avionics Weight + 868 Square Root(BTU cooling) +
0.064 Engine Weight

8 cases used
```

Predictor	Coef	StDev	T	P
Constant	-5287	5556	-0.95	0.395
Avionics Weight	2.611	1.326	1.97	0.120
SQR(BTU cooling)	868.4	740.3	1.17	0.306
Engine Weight	0.0635	0.3255	0.20	0.855

```
S = 4433          R-Sq = 83.7% Average = $14,487
```

Depot Engine Maintenance (FY05$ per flying hour per engine) (not used)

```
DM/FH/Engine = - 162 + 1.53 SQR(engine weight) + 0.00597 engine thrust

9 cases used
```

Predictor	Coef	StDev	T	P
Constant	-161.9	102.8	-1.57	0.166
sqr(eng wgt)	1.5348	0.7323	2.10	0.081
eng thrust	0.005966	0.003521	1.69	0.141

```
S = 88.96         R-Sq = 65.2% Average = $630
```

Depot Engine Maintenance (FY05$ per mission per engine)

```
Engine Depot Maintenance per mission = - 1682 + 0.248 ENG WGT + 4.82 KVA MAX

10 cases used
```

Predictor	Coef	StDev	T	P
Constant	-1682.4	532.4	-3.16	0.016
ENG WGT	0.24837	0.03481	7.14	0.000
KVA MAX	4.821	1.920	2.51	0.040

```
S = 893.6         R-Sq = 94.3% Average = $ 3,172
```

Depot Maintenance (FY05$ per vehicle)

```
Depot Maintenance per vehicle = - 823068 + 801530 sqr eng + 15618 ACTUATORS +
44.9 AVCS WGT - 7357 SQR(wet area)

10 cases used
```

Predictor	Coef	StDev	T	P
Constant	-823068	270668	-3.04	0.029
sqr eng	801530	221698	3.62	0.015
ACTUATOR	15618	4453	3.51	0.017
AVCS WGT	44.90	13.37	3.36	0.020
sqr wetarea	-7357	3661	-2.01	0.101

```
S = 206385        R-Sq = 92.1%
```

Annual reoccurring cost (CES 2.3.2.1) = missions per year x (hours per mission x Depot Level repair +

engine hours per mission (or cycles) x Depot Engine Maintenance x number of engines / vehicle) + Depot Maintenance x number of vehicles

4.3 Modifications (CES 2.3.2.2)

4.3.1 Definition

Modifications are the tasks required to perform modifications on a flight element and the tests and evaluation of those modifications. This is the cost of installing modification material to aircraft, ground support equipment, and training equipment to enable that equipment to perform mission essential tasks and to improve safety, reliability, or maintainability. This activity does not include new capabilities.

4.3.2 Shuttle Costing

Activity	FY05 $M Annual
Orbiter Modifications	8.291
SRB Modifications	0.128
ET Modifications	0.128
Total Modification	8.547

Table 4-4 Shuttle Modification Cost (Source: 1994 Access to Space Study)

It is assumed that modifications are not driven by flight rate but rather represent an annual average cost to correct problems and improve safety, reliability, and maintainability.

Annual reoccurring cost (CES 2.3.2.2)
= 8.291 x (vehicle wetted area / shuttle wetted area) x Nbr vehicles / 4
+ .128 x (SRB empty weight in 1000 lbs / 193) x Nbr SRBs /2
+ .128 x (ET empty weight in 1000 lbs / 78.1) x Nbr ETs

4.3.3 Aircraft Costing[29]

Aircraft modifications are usually correlated with the unit procurement cost (UPC) or flyaway cost.

	Flyaway Cost FY05 $M	Vehicle	Flyaway Cost FY05 $M
A010	11.1	C141	45.6
B001	264.8	E003	126.0
B002	1082.4	E004	100.2
B052	57.6	F004	11.7
C005	143.5	F015	31.2
C009	19.9	F016	18.0
C010	82.9	T037	1.1
C017	228.0	T038	4.1

[29] Alternate approach from Navy fixed-wing study: modification procurement = .0041 x FC_{100} ; modification installation = .18 x mod procurement where FC_{100} = average flyaway cost of first 100 aircraft.

	Flyaway Cost FY05 $M	Vehicle	Flyaway Cost FY05 $M
C130	36.6	T043	22.2
C135	27.9		

Table 4-5 Aircraft Flyaway Cost[30] (Source: AFI 65-503 Table A10-1 FY05 $M)

AF: Modification Kits. Included are the cost of procuring and installing modification kits and modification kit initial spares for aircraft, and associated support equipment, and training equipment. The modifications included are those needed to achieve acceptable levels of safety, overcome mission capability deficiencies, improve reliability, or reduce maintenance costs. Excluded are modifications that are undertaken to provide operational capability not called for in the original design or performance specifications.

The following regression equation was derived using the data in Table 4-5.

```
Log(flyaway cost)(FY05 $M) = - 7.01 + 0.687 Log(dry weight)+ 0.329
Log(avionics weight)+ 0.110 Log(number of hydraulic subsystems)

14 cases used
```

Predictor	Coef	StDev	T	P
Constant	-7.0055	0.8844	-7.92	0.000
ln(dry wgt)	0.6873	0.1323	5.20	0.000
ln(av wgt)	0.3290	0.1299	2.53	0.030
ln(hyd sUbsys)	0.1103	0.1997	0.55	0.593

```
S = 0.3861      R-Sq = 93.5%
```

The following CER is adopted from the Thomas May Study [31]:

Annual reoccurring cost (CES 2.3.2.2) = 9220 x number vehicles x (unit flyaway cost)$^{.74116}$ / 10^6

4.4 Spares (CES 2.3.2.3)

4.4.1 Definition

Spares include both initial and recurring spares required for both launch elements and GSE support. Replenishment of major elements, which reach wear-out such as engines and solid rocket casings, will be carried as spares. Vehicle replacement due to exceeding design life would not be carried here.

4.4.2 Shuttle Costing

30 The factors in this table represent the approximate original cost of aircraft. The following items are included in unit flyaway cost under Appropriation 3010 (Aircraft Procurement): Airframe, Propulsion, Electronics, Avionics, engineering changes, Government Furnished Equipment (GFE), First destination transportation (unless a separate line item), System and Program Management, Warranties, Recurring costs, Nonrecurring costs, and advance buy costs. Unit flyaway cost does not include: Research, Development, Test and Evaluation (RDT&E) expenditures, weapons and armaments, peculiar ground support equipment, peculiar test equipment, technical data, initial and replenishment spares.

Activity	FY05 $M Annual	FY05 $M per Flight
ENG-New Hardware Spares	57.1	7.14
ORB&GSE-Spares	56.5	7.06
Orbiter Spares & Integration	185.1	23.14
SSME Production	141.8	17.73
RSRM/SRB Production	67.3	8.42
Orbiter/ET Disconnects	9.8	1.23
Total Spares	517.7	64.72

Table 4-6 Shuttle Spares Cost (Source: 1994 Access to Space Study)

Spares	
LRU Removals per mission	349.5
Mean number in repair	1287.1
Spares requirement	2406.7

Table 4-7 Shuttle Spares Requirement (Source: RMAT 2004 -V5.9.2)[31]

Activity	FY05 $M Annual	FY05 $M per Flight
ENG-New Hardware Spares	57.1	
ORB&GSE-Spares		7.06
Orbiter Spares & Integration		23.14
SSME Production		17.73
RSRM/SRB Production		8.42
Orbiter/ET Disconnects		1.23
Total Spares	57.1	57.58

Table 4-8 Annual versus Mission Spares Cost (Source: Table 4-6)

Annual reoccurring cost (CES 2.3.2.3) = 57.1 + [(7.06 + 23.14) x (LRU removals per mission / 350)
+ (17.73 x Number Main Engines / 3) x (thrust per engine in 1000 lbs / 375)
+ 8.42 x (SRB empty weight in 1000 lbs./193) x Number SRBs / 2 + 1.23 x Number ET (ET empty weight in 1000 lbs / 78.1) x flight rate

4.4.3 Aircraft costing

Initial Spares

31 Import of sts8-BM from RMAT2003, Version 4.1.0. STS RMAT2004 Benchmark Case; 20% serial work on tiles, main propulsion, RCS, OMS, APU and 10% serial work on separation.

Aircraft	Initial /FH FY05$	Aircraft	Initial /FH FY05$
A010	$5,219	E004	$6,639
B001	$75,363	E008	$6,955
B002	$61,751	F015A	$28,158
B052	$36,582	F015E	$29,000
C005	$22,091	F016	$9,800
C130	$3,146	KC135	$6,186
C135	$6,524	T037	$505
C141	$8,707	T038	$1,435
E003	$19,442	T043	$366

Table 4-9 Initial requirement for recoverable items spares (no safety levels)[32]
(Source: AFMC D200A Requirement Management System (RMS) March 03 production cycle data)

Aircraft	Initial /FH FY05$	Aircraft	Initial /FH FY05$
A010	$10,333	E004	$23,353
B001	$201,085	E008	$14,300
B002	$128,610	F015A	$50,779
B052	$74,938	F015E	$53,713
C005	$45,624	F016	$17,308
C130	$8,697	KC135	$12,399
C135	$12,927	T037	$808
C141	$28,172	T038	$2,048
E003	$65,829	T043	$1,228

Table 4-10 Initial requirement for recoverable items spares (includes safety levels)[33]
(Source: AFMC D200A Requirement Management System (RMS) March 03 production cycle data)

Reoccurring Spares Cost

	Cost per Flying Hour (FY05$)			
Aircraft	**FY02**	**FY03**	**FY04**	**Average**
A010	$988	$1,079	$1,264	$1,111
B001	$59,189	$21,630	$25,936	$35,585
B002	$19,462	$22,451	$31,921	$24,612
B052	$13,339	$15,360	$30,916	$19,871
C005	$21,980	$11,442	$10,440	$14,621
C130	$1,156	$2,424	$2,914	$2,165
C135	$2,683	$1,606	$4,574	$2,954

[32] Results are from a special D200A computation that assumed no assets were in the system. Costs are those to fill the logistic pipeline. No safety level is included.

[33] Results are from a special D200A computation that assumed no assets were in the system. Costs are those to fill the logistic pipeline. Safety level is included.

C141	$5,075	$4,062	No data	$3,046
E003	$8,723	$12,781	$13,177	$11,560
E004	$9,100	$4,349	$16,053	$9,834
E008	$3,481	$5,088	$6,181	$4,917
F015A	$8,056	$9,206	$11,929	$9,730
F015E	$8,906	$13,282	$9,831	$10,673
F016	$4,196	$4,180	$4,455	$4,277
F022	No data	No data	$5,957	$1,986
KC135	$2,303	$2,231	$2,807	$2,447
T037	$117	$438	$153	$236
T038	$1,441	$420	$241	$700
T043	$60	$244	$711	$338

Table 4-11 Annual replenishment buy requirements for recoverable items spares (Source: AFMC D200A Requirement Management System[34])

Recoverable Replenishment Spares (reoccurring annual costs FY05$)

Spares/Flying Hour = 16,766 + 1.46 Engine weight – 2,996 SQR[length + wing span] + 569 Number of Avionics Subsystems

```
10 cases used

Predictor           Coef         StDev          T        P
Constant           16766          3568       4.70    0.003
ENG WGT           1.4551        0.1941       7.50    0.000
SQR(len+wing)    -2996.3         561.8      -5.33    0.002
AVCS TOT           568.7         166.3       3.42    0.014

S = 2017          R-Sq = 94.0%
```

Annual reoccurring cost (CES 2.3.2.3) = Spares/ Flying Hour x mission hours per year

4.5 Expendables (CES 2.3.2.4)

4.5.1 Definition

Expendables - Includes all elements that are expended on a per flight basis (e.g. ET for Shuttle, Castors for Delta).

4.5.2 Shuttle Costing

Shuttle External Tank Data	
Empty weight	35,425 kilograms (78,100 pounds)
Propellant weight	719,115 kilograms (1,585,379 pounds)
Liquid oxygen	616,496 kilograms (1,359,142 pounds)
Liquid hydrogen	102,619 kilograms (226,237 pounds)

[34] Costs were determined using an asset based computation that includes a variable safety level based upon an aircraft availability goal.

Shuttle External Tank Data	
Propellant Volume	526,126 gallons (1,991,604 liters)
Liquid oxygen tank	143,060 gallons (541,541 liters)
Liquid hydrogen tank	383,066 gallons (1,450,063 liters)

Table 4-12 Shuttle ET Data (Source: http://spaceflight.nasa.gov/shuttle/reference/basics/et/index.html)

Activity	FY05 $M Annual	FY05 $M per Flight
Total ET	475.0	59.4

Table 4-13 ET Cost (Source: 1994 Access to Space Study)

Shuttle and Aircraft Mode:

Cost per flight = 59.4 x Number ETs per flight x (ET propellant volume in 1000 gal. / 526)

Annual reoccurring cost (CES 2.3.2.4) = Cost per flight x flight rate

4.5.3 Aircraft Costing

The Air Force defines expendable or consumable items as repair parts, assemblies, subassemblies, and material consumed in the maintenance and repair of the primary system, associated support equipment, and unit level training devices. These costs are accounted for at the base or retail level as Flying Hour Consumable Supplies (FHCS) and at the depot level are included in the depot maintenance costs. This cost element is set to zero for the aircraft mode.

4.6 Consumables (CES 2.3.2.5)

4.6.1 Definition

Consumables - Includes the cost of all fluids and elements that are replenished after each flight. (e.g. LOX, LH2, Lithium Hydroxide containers, etc.)

4.6.2 Shuttle Costing

Activity	FY05 $M* per flight
Total Propellant from Launch Ops (KSC)	$2.631
SRM/SRB Propellant (total)	$16.264

Table 4-14 Propellant Cost (Source: 1994 Access to space study)

Consumable	Lbs / flight
Solid Fuel	1,107,000 / SRB
ET liquid oxygen	1,359,142 (volume of 19,563 ft^3)
ET liquid hydrogen	226,237 (volume of 53,518 ft^3)
RCS fuel	923 / RCS
RCS Oxidizer	1464 / RCS

Table 4-15 Shuttle Fuel Specifications (Source: http://spaceflight.nasa.gov/shuttle/reference/basics/et/index.html)

Cost per flight = $2.631 x (propellant volume in 1000 gal. / 526) + $16.264 x (Solid fuel weight /

2,214,000)

Annual reoccurring cost (CES 2.3.2.5) = Cost per flight x flight rate

4.6.3 Aircraft Costing

Vehicle	FY05$ per flying hr	Vehicle	FY05$ per flying hr
A010	$593	C141	$1,977
B001	$3,524	E003	$2,205
B002	$2,061	E004	$4,687
B052	$3,087	F015	$1,500
C005	$3,298	F016	$837
C009	$938	F117	$999
C010	$2,609	T001	$181
C017	$2,800	T037	$164
C130	$702	T038	$373
C135	$1,644	T043	$799

Table 4-16 Aviation fuel cost. (Source: AFI 65-503, Attachment 2-1)

Alternate Aircraft Mode (not used):

```
Aviation fuel per flying hr (FY05$) = - 114 + 4.19 sqr dyr wt + 0.0395 ENG WGT

20 cases

Predictor          Coef        StDev          T        P
Constant         -113.5        246.9      -0.46    0.651
sqr dyr           4.189        1.761       2.38    0.029
ENG WGT         0.03948      0.02783       1.42    0.174

S = 444.3          R-Sq = 89.0%
```

Cost per flight = $ / lb liquid fuel x (1 + boil-off rate) x lbs of liquid fuel per flight + $ / lb liquid oxidizer x (1 + boil-off rate) x lbs of liquid oxidizer per flight + $ / lb solid rocket propellant x lbs of propellant per flight

Annual reoccurring cost (CES 2.3.2.5) = Cost per flight x flight rate

4.7 Inventory Management & Warehousing (CES 2.3.2.6)

4.7.1 Definition

Inventory Management & Warehousing consists of the cost of managing, procuring, receiving, and storing supplies required to support the systems mission. This includes GSE as well as vehicle supplies.

4.7.2 Shuttle Costing

Activity	FY05 $M Annual
ENG-Inventory Management & Warehousing	8.7
ORB & GSE-Manpower to Support Logistics, Procurement, Etc.	42.2
Receiving Service Center	1.3
Supply	36.0
Procurement Service Center	4.2
Total	92.4

Table 4-17 Supply Support Costs (Source: 1994 Access to Space Study)

Activity	Fixed costs ($M)	Variable (mission) costs ($M)
ENG-Inventory Management & Warehousing	8.7	
ORB & GSE-Manpower to Support Logistics, Procurement, Etc.		42.2
Receiving Service Center	1.3	
Supply		36.0
Procurement Service Center	4.2	
Total	14.2	78.2

Table 4-18 Fixed versus Variable Supply Costs

Cost per flight = (78.2/8) x (LRU removals per mission / 350)

Annual reoccurring cost (CES 2.3.2.6) = (14.2 + Cost per flight x flight rate)

4.7.3 Aircraft Costing

Annual reoccurring cost (CES 2.3.2.6) = fixed percent (default 12%) x Spares (CES 2.3.2.3) annual reoccurring cost

4.8 Training (CES 2.3.2.7)

4.8.1 Definition

Training includes the cost for training organizational and depot level personnel direct labor.

4.8.2 Shuttle Costing

Activity	FY05 $M Annual
Launch Team Training System (LTTS) Program	1.79
Training	17.99
Total	19.77

Table 4-19 Shuttle Training Costs (Source: 1994 Access to Space Study)

2.3.1.2 Organizational Maintenance	Labor Head Count	FY05 $M
ENG-Anomaly Resolution	143	28.445
ORB&GSE-Tile Spares & Maintenance	153	33.547
Orbiter Maintenance	807	79.084
Orbiter Shop Operations	117	11.352
Orbiter Tile Operations	279	22.577
2.3.2.1 Depot Maintenance		
ENG-Hardware Refurbishment	98	26.914
ORB&GSE-Overhaul & Repair	431	82.401
Total	2028	284.321
Launch Support Services	350	97.1

Table 4-20 Maintenance Head Counts (Source: 1994 Access to Space Study)[35]

Activity	Training Cost	Launch Operations Cost
Launch Team Training System (LTTS) Program	1.79	97.07
		Maintenance Cost
Maintenance Training	17.99	284.321

Table 4-21 Training Driver Costs

Annual reoccurring cost (CES 2.3.2.7) = $17.99 x [Organizational Maintenance Cost (CES 2.3.1.2) + Depot Maintenance Cost (CES 2.3.21)] / 284.321 + $1.79 x Launch Operations Cost (CES 2.3.1.7) / 97.07

Initial cost (CES 2.3.2.7) = Annual reoccurring cost (CES 2.3.2.7)

4.8.3 Aircraft Costing

Officer Training

Specialty	Course Length (Weeks)	Total FY05$
Aircraft Maintenance	14.0	$26,488

35 Created from DOS-Budget Baseline-V8g on 6/7/01

Missile Maintenance	5.2	$14,223

Table 4-22 Maintenance Officer Training Cost[36] (Source: AFI 65-503 Attachment A18-1B, Mar-03)

Enlisted Training

Variable Cost by Enlisted Air Force Specialty Training

Air Force Maintenance Specialty	Course length (wks)	Total FY03$**	cost/week
F-15 Avionic Test Station/Aircraft Component Apprentice	30.6	$37,992	$1,241.56
A-10/F-16/F-117 Avionic Test Station/Acft Comp	29.4	$35,950	$1,222.77
B-1/B-2/C-17 Avionic Test Station/Acft Comp	28.2	$34,513	$1,223.87
Avionics Sensors Maintenance Apprentice	28.6	$34,914	$1,220.78
Electronic Warfare Avionics Sys Test Station/Comp	25.2	$31,147	$1,235.99
F-15 Avionics Attack Control Systems Apprentice	28.6	$34,701	$1,213.34
A-10 Avionic Attack and Control Systems Apprentice	23.8	$29,006	$1,218.75
F-15 Avionic Instrument & Flight Control System Apprentice	29.7	$36,077	$1,214.70
A-10 Avionic Instrument & Flight Control System Apprentice	28.7	$34,871	$1,215.03
F-15 Avionic Comm, Nav/Pen Aids System Apprentice	29.6	$34,842	$1,177.08
A-10 Avionic Comm, Nav/Pen Aids System Apprentice	28.8	$33,834	$1,174.79
F16 C/D Avionic Systems Apprentice	33.0	$37,529	$1,137.25
Tactical Aircraft Maintenance	29.5	$36,432	$1,235.00
Fighter Aircraft Maintenance Apprentice (F-16)	29.5	$36,432	$1,235.00
Fighter Aircraft Maintenance Apprentice (F-117A)	31.5	$39,202	$1,244.51
Fighter Aircraft Maintenance Apprentice (A-10)	28.1	$34,236	$1,218.36
Fighter Aircraft Maintenance Apprentice (U-2)	10.9	$14,117	$1,295.17
Aerospace Maintenance Apprentice (C-9)	11.0	$14,105	$1,282.27
Aerospace Maintenance Apprentice (C-130)	24.2	$29,206	$1,206.85
Aerospace Maintenance Apprentice (C-5)	11.0	$14,091	$1,281.04
C-17 APG Crew Chief	10.9	$14,018	$1,286.04
Maintenance Apprentice	19.9	$26,202	$1,319.31
B-1B Aerospace Maintenance Apprentice	20.9	$26,845	$1,284.46
B-2 Aerospace Maintenance Apprentice	17.6	$24,041	$1,365.98
B-52 Aerospace Maintenance Apprentice	18.1	$22,363	$1,235.50
Aerospace Maintenance Apprentice	19.4	$25,024	$1,291.54
Aerospace Maint Appr (C-135)	19.0	$22,959	$1,208.36
Aerospace Maint Appr (E-3)	24.9	$33,621	$1,350.23
Aerospace Maint Appr (KC-10)	18.9	$22,800	$1,206.36
Aerospace Maint Appr (KC-10A)	19.0	$22,874	$1,203.88
Aerospace Maint Appr (C-135,E-3,KC-10/10A)	20.5	$25,563	$1,250.04
Aerospace Maint Appr (H-53 MRT)	29.6	$34,046	$1,150.22
Aerospace Maint Appr (UH-60)	21.5	$28,650	$1,332.55
Aerospace Maint Appr (H-53, UH-60)	25.6	$31,348	$1,226.93
Comm/Navigation/Mission Systems Apprentice	31.0	$37,190	$1,199.67
B-1 and B-2 Avionic Systems Apprentice	31.0	$33,763	$1,089.13

[36] Initial Skill Training - Officer acquisition costs are NOT included in this table. Course length is the length adjusted for training time expended on attrited students

Air Force Maintenance Specialty	Course length (wks)	Total FY03$**	cost/week
B-1 and B-2 Systems Specialist	27.5	$32,731	$1,190.23
Airborne Surveillance Radar Systems Apprentice	25.4	$31,182	$1,227.62
Aerospace Propulsion Apprentice, Jet Engines	18.3	$22,039	$1,202.11
Aerospace Propulsion Appr, Turboprop/Turboshaft Engine	20.5	$23,523	$1,147.46
Aerospace Ground Equipment Apprentice	28.5	$29,932	$1,050.23
Aircrew Egress Apprentice	13.3	$17,589	$1,322.50
Aircraft Fuel Systems Apprentice	13.8	$15,488	$1,122.34
Aircraft Hydraulics Systems Apprentice	16.2	$18,635	$1,150.28
Aircraft Electrical & Environmental Systems Appr	25.3	$27,913	$1,103.26
Aircraft Metals Technology Apprentice	26.4	$30,364	$1,150.14
Nondestructive Inspection Apprentice	16.7	$19,666	$1,177.63
Aircraft Structural Maintenance Apprentice	22.7	$23,996	$1,057.09
Survival Equipment Apprentice	19.7	$22,258	$1,129.84
Average	23.3	$28,160	$1,215
Basic Military Training (BMT) without specialty training	6.3	$8,109	$1,287

Table 4-23 Enlisted Maintenance Training[37] (Source: AFI 65-503, Attachment A18-1A, Mar-03)

	FY05 End Strength	Percent
Officer	69,300	.195
Enlisted	286,400	.815

Table 4-24 Officer versus Enlisted End Strength (Source: Department of the Air Force FY2006/2007 Budget Estimate Military Personnel Appropriation, February 2005)

Aircraft Maintenance Officer Training consists of a 14-week course with a cost of $26,488 in FY05 dollars. Maintenance technician specialty training costs were determined by taking the Appendix A-18 cost per course per individual, subtracting basic military training (BMT) costs, adjusting to FY05 dollars, and averaging where appropriate. These averages are then multiplied by the number of technicians within each specialty to obtain an initial training cost. Using a turnover rate, a reoccurring technician training cost is then obtained.

Avionics	FY05$
F-15 Avionic Test Station/Aircraft Component Apprentice	$31,070
A-10/F-16/F-117 Avionic Test Station/Acft Comp	$28,947
B-1/B-2/C-17 Avionic Test Station/Acft Comp	$27,453
Avionics Sensors Maintenance Apprentice	$27,870
Electronic Warfare Avionics Sys Test Station/Comp	$23,953
F-15 Avionics Attack Control Systems Apprentice	$27,649
A-10 Avionic Attack and Control Systems Apprentice	$21,727
F-15 Avionic Instrument & Flight Control System Apprentice	$29,079
A-10 Avionic Instrument & Flight Control System Apprentice	$27,826

37 Includes cost per graduate for training courses required for specific AFSCs at the basic skill level and acquisition costs (including the costs of recruiting, initial travel, and initial clothing issued) and the cost of basic training at the Air Force Military Training Center (enlisted only), student pay and allowances.

F-15 Avionic Comm, Nav/Pen Aids System Apprentice	$27,795
A-10 Avionic Comm, Nav/Pen Aids System Apprentice	$26,747
F16 C/D Avionic Systems Apprentice	$30,589
Average Avionics Training Cost	$27,559
Crewchiefs (General maintenance)	FY05$
Tactical Aircraft Maintenance	$29,449
Fighter Aircraft Maintenance Apprentice (F-16)	$29,449
Fighter Aircraft Maintenance Apprentice (F-117A)	$32,328
Fighter Aircraft Maintenance Apprentice (A-10)	$27,165
Fighter Aircraft Maintenance Apprentice (U-2)	$6,247
Aerospace Maintenance Apprentice (C-9)	$6,234
Aerospace Maintenance Apprentice (C-130)	$21,935
Aerospace Maintenance Apprentice (C-5)	$6,220
C-17 APG Crew Chief	$6,144
Maintenance Apprentice	$18,811
B-1B Aerospace Maintenance Apprentice	$19,481
B-2 Aerospace Maintenance Apprentice	$16,565
B-52 Aerospace Maintenance Apprentice	$14,820
Aerospace Maintenance Apprentice	$17,587
Aerospace Maint Appr (C-135)	$15,440
Aerospace Maint Appr (E-3)	$26,525
Aerospace Maint Appr (KC-10)	$15,275
Aerospace Maint Appr (KC-10A)	$15,351
Aerospace Maint Appr (C-135,E-3,KC-10/10A)	$18,148
Aerospace Maint Appr (H-53 MRT)	$26,968
Aerospace Maint Appr (UH-60)	$21,357
Aerospace Maint Appr (H-53, UH-60)	$24,162
Average General Maintenance Training Cost	$18,894
Propulsion	FY05$
Aerospace Propulsion Apprentice, Jet Engines	$14,483
Aerospace Propulsion Appr, Turboprop/Turboshaft Engine	$16,026
Average Propulsion Training Cost	$15,255
Other Maintenance	FY05$
Aircraft Fuel Systems Apprentice	$7,672
Aircraft Hydraulics Systems Apprentice	$10,944
Aircraft Electrical & Environmental Systems Appr	$20,590
Aircraft Structural Maintenance Apprentice	$16,518
Survival Equipment Apprentice	$14,711
Aircrew Life Support Apprentice	$7,238
Aircrew Egress Apprentice	$9,857
Missile & Space Systems Elec Maint Apprentice	$30,967

Table 4-25 Maintenance Training Costs grouped by Specialty (Source: Table 4-23)

	Workcenter	AF Specialty	Training Cost
1	1.00 Wing Group	Structural	$16,518
2	2.00 Tail Group	Structural	$16,518
3	3.00 Body Group	Structural	$16,518

	Workcenter	AF Specialty	Training Cost
4	3.10 Tanks-Lox	Fuel Systems	$7,672
5	3.20 Tanks-Lh2	Fuel Systems	$7,672
6	4.10 Iep-Tiles	Structural	$16,518
7	4.20 Iep-Tcs	Electrical & Environmental	$20,590
8	4.30 Iep-Pvd	Electrical & Environmental	$20,590
9	5.00 Landing Gear	Structural	$16,518
10	6.00 Propulsion-Main	Propulsion	$15,255
11	6.10 Propulsion - Mps	Propulsion	$15,255
12	7.00 Propulsion-Rcs	Propulsion	$15,255
13	8.00 Propulsion-Oms	Propulsion	$15,255
14	9.10 Power-Apu	Missile & Space Sys Elec	$30,967
15	9.20 Power-Battery	Missile & Space Sys Elec	$30,967
16	9.30 Power-Fuel Cell	Missile & Space Sys Elec	$30,967
17	10.00 Electrical	Missile & Space Sys Elec	$30,967
18	11.00 Hydraulics	Hydraulics	$10,944
19	12.00 Aero Surf Actuators	Structural	$16,518
20	13.10 Avionics-Gn&C	Avionics	$27,559
21	13.20 Av-Health Monitor	Avionics	$27,559
22	13.30 Avionics-Comm & Track	Avionics	$27,559
23	13.40 Av-Displays & Contr	Avionics	$27,559
24	13.50 Avionics-Instruments	Avionics	$27,559
25	13.60 Avionics-Data Proc	Avionics	$27,559
26	14.10 Environmental Control	Electrical & Environmental	$20,590
27	14.20 Ecs-Life Support	Life Support	$7,238
28	15.00 Personnel Provisions	Crewchiefs	$18,894
29	16.10 Rec & Aux-Parachutes	Survival Equipment	$14,711
30	16.20 Rec & Aux-Escape Sys	Egress	$9,857
31	16.30 Rec&Aux-Separation	Structural	$16,518
32	16.40 Rec&Aux-Cross Feed	Structural	$16,518
33	16.50 Rec & Aux Docking Sys	Structural	$16,518
34	16.60 Rec&Aux Manipulator	Structural	$16,518
35	17.00 General	Crewchiefs	$18,894
36	20.00 Ballast	N/a	$0
37	30.00 User Specified	Crewchiefs	$18,894

Table 4-26 Aircraft Maintenance Training Costs by WBS

Additional maintenance (overhead) training is based upon the average from the following maintenance specialties:

Air Force Specialty	(Weeks)	FY05$
Aerospace Ground Equipment Apprentice	22.2	$22,690
Precision Measurement Equipment Lab Apprentice	28.7	$33,751
Maintenance Data Systems Analysis Apprentice	11.3	$12,460
Maintenance Scheduling Apprentice	6.4	$7,083
Supply Management Apprentice	6.9	$7,093
Supply Systems Analysis Apprentice	10.3	$10,640
Nondestructive Inspection Apprentice	10.4	$12,016
Average		$15,105

Table 4-27 Maintenance Overhead Training Costs

Organizational level maintenance training:

- Initial technician training cost = $\sum$ Number of technicians specialty x individual cost of course i
- Initial overhead training cost = fraction non-management (e.g. enlisted) x \$15,105 x total overhead personnel + (1-fraction non-management)[38] x \$26,488 x total overhead personnel
- Initial organization level training cost = Initial Technician training cost + Initial Overhead Training Cost

Depot level maintenance training:

Initial depot level training cost = Depot maintenance cost (CES 2.3.2.1) x (Initial organization level training cost / Organizational maintenance Cost (CES 2.3.1.2)

Initial cost (CES 2.3.2.7) = (Initial organization level training cost + Initial depot level training cost) / 10^6

Annual reoccurring cost (CES 2.3.2.7) = Personnel turnover rate x Initial cost (CES 2.3.2.7)

4.9 Documentation (CES 2.3.2.8)

4.9.1 Definition

Documentation - Includes the functions required to document and keep current the maintenance manuals, requirements directives, etc.

4.9.2 Shuttle Costing

Activity	FY05 $M
Flight Data Support	13.27

Table 4-28 Shuttle Documentation Cost (Source: Access to space study)

Documentation costs are assumed to be proportional to the number of subsystems and components. The number of components within a subsystem is assumed to be proportional to its weight. The Shuttle has 26 major subsystems plus documentation for the external tank (ET), Solid Rocket Booster (SRB), and Mobile Launch Platform (MLP). Therefore:

Scale Factor = $W = \dfrac{\sum_{i=1}^{n} \dfrac{w_i}{ws_i}}{29}$ where w_i = weight of the i[th] subsystem, ws_i = weight of the i[th] Shuttle subsystem, and n = number of vehicle subsystems + ET + SRB + MLP where ET = 1, SRB = 1, and MLP = 1 if part of the system; 0 otherwise.

If for k, $ws_k = 0$, then $\dfrac{w_k}{ws_k} = 1$

[38] Historically the number of officers in a maintenance wing is approximately 2 percent of its total manning [May, Thomas O&S Cost estimates]

Annual reoccurring cost (CES 2.3.2.8) = \$13.27 x *W*

4.9.3 Aircraft Costing

The Hypervelocity Aerospace Vehicle cost study developed the following CERs for data cost by subsystem. These have been adjusted for FY05 \$M per mission.

Structure Data = 0.000752 x Max takeoff wgt$^{.6394}$ (weight in lb.)
Landing Gear Data = .000396 x TFF$^{.6664}$ x (sink speed)$^{.30877}$ (TFF = date of first flight in months since Jan. 1950, sink speed = 9)
Payload Data = .01 x UPC (unit flyaway cost)
Avionics Data = .262792 x Avionics Weight$^{.091207}$
Electrical Data = 7.16 x 10^{-5} x Max KVA$^{1.0292}$
Hydraulics Data = .00137 x Nbr Actuators$^{.95341}$
ECLS Data = .053683 x Avionics weight$^{.18719}$
Flight Provisions Data = 2.87 x 10^{-5} x (flight crew + mission crew)$^{.70674}$ x TFF$^{.9167}$
Docking Data = 9.55 x 10^{-7} x Max take-off wgt$^{.6394}$

Although the Hypervelocity Aerospace Vehicle cost study did not include engine O&S costs because of engine complexity, the assumption is made here that engine documentation would be no less than that of avionic system and therefore, the avionics data CER will be utilized for engines including OMS and RCS if present.

Engine Data = .262792 x Engine Weight$^{.091207}$

4.10 Transportation (CES 2.3.2.9)

4.10.1 Definition

Transportation- Includes the cost of transportation of elements to the launch site from the site of manufacturing as well as return from contingency landing sites? This CES does not include package handling and transportation for supply inventory.

4.10.2 Shuttle Costing

Activity	FY05 \$M	FY05 \$M per Flight
ENG-Transportation	1.66	0.207
Transportation	5.87	0.733
Total	\$7.53	0.941

Table 4-29 Shuttle Transportation Costs (Source: Access to space study)

It is assumed that the activities included within the Shuttle transportation cost are delivery of an ET and transport of the 2 recovered SRBs each mission. In addition, OMDP roundtrips, and an orbiter recovery from an alternate site would incur transportation costs. Three of the 8 orbiter landings were at Edwards AFB and there was one OMDP roundtrip. Therefore, on a per flight basis, there were 3 5/8 units. Initial

costs assume a single transport of the vehicle and any ETs and SRBs to the launch site from the manufacturer's facility.

Activity	FY05 $M	FY05 $M per Flight
ENG-Transportation	1.66	
Transportation		0.733

Table 4-30 Annual versus Mission Transportation Costs

Cost per flight = .733 x (Nbr ET + Nbr SRB + probability of off-site landing + 2 / depot overhaul frequency) / 3.625

Initial cost (CES 2.3.2.9) = .733 x (Nbr ET + Nbr SRB + 1) / 3.625

Annual reoccurring cost (CES 2.3.2.9) = 1.66 + Cost per flight x flight rate

4.10.3 Aircraft Costing

Aircraft are periodically flown to the depot or a manufacturer's site for overhaul and engineering upgrades. Aircraft reimbursement rates reflect the total operating cost per hour and are provided in Table 4-30 for selected aircraft.

Vehicle	$/Flying Hour (FY05)	Vehicle	$/Flying Hour (FY05)
A010	4038	C141	7502
B001	24128	E003	9947
B002	13967	E004	52525
B052	14235	F015	12314
C005	13673	F016	5274
C009	6901	F117	18624
C010	9695	T001	1377
C017	5795	T037	485
C130	3733	T038	1478
C135	3733	T043	3827

Table 4-31 Aircraft O&M Cost per Flying Hour[39] (Source: AFI 65-503 A15-1, November 2004)

Transportation cost in the aircraft mode is based upon the Programmed Depot Maintenance (PDM) schedule and the Engine Overhaul Schedule (EOH). It is assumed that the vehicle site return rate in this case includes the frequency that the vehicle is flown to the depot or manufacturer for planned overhaul. To estimate the cost, the following CER was derived from the data provided in Table 4-31.

```
The regression equation is
$ per Flying Hr = 1896 + 122 x SQR[Dry Weight] - 142 x (Length + Wing Span) +
569 Crew size
```

39 Included are logistics costs (fuel, depot maintenance, depot level reparables and consumables), CLS costs, and personnel costs for aircrew.

20 cases used

Predictor	Coef	StDev	T	P
Constant	1896	3162	0.60	0.557
SQR(dry wgt)	122.44	34.49	3.55	0.003
LEN_WING	-142.36	47.02	-3.03	0.008
CREwSIZE	569.2	258.3	2.20	0.043

S = 6511 R-Sq = 73.6% Average = $10,663

Non-mission landings are defined to be landings at an alternate site from the launch site and landing at and returning from a depot or manufacturer's site. A worst case flying time of 5.5 hours is assumed. This is based on a vehicle being transported at 500 mph over a distance in excess of 2700 miles (e.g. KSC to Seattle). These costs support Programmed Depot Maintenance (PDM) and Engine Overhaul Program (EOH). If ETs and SRBs are used, their transport costs are computed similar to that of the main engines.

Initial cost is based upon separate transport of the vehicle, engines, ETs, and SRBs from the manufacturer's facility to the launch site.

Initial cost (CES 2.3.2.9) = 5.5 x $ per Flying Hr x (1 + number engines per vehicle + number ET + number SRB)

Annual reoccurring cost (CES 2.3.2.9) = 5.5 x $ per Flying Hr x Number of Off-site and non-mission landings per year + 5 x $13,673 x 2 (round-trip) x number engines per vehicle x flight rate / EOH frequency + 5 x $13,673 x (number ET + number SRB) x Flight Rate

4.11 Support Equipment (CES 2.3.2.10)

4.11.1 Definition

Support Equipment consists of the costs incurred to replace equipment that is needed to operate or support the vehicles, their subsystems, training systems, and other associated support equipment. This includes all items required in the support of vehicle processing that are not classified as facilities such as GSE, SFE and major elements such as the Boeing 747 used for transportation and the recovery ships used for retrieval. The support equipment being replaced (e.g., tools and test sets) may be unique to the vehicle or it may be common to a number of other systems in which case the costs must be allocated among the respective systems. Excluded are those items that have been identified as refurbishment items such as the MLP. These items are distinguished in that they are refurbished and not replaced and their refurbishment rate is based upon the flight rate. Note: This element addresses replacement equipment only. The costs of initial support equipment are specifically excluded.

4.11.2 Shuttle Costing

Activity	FY05 $M
GSE Sustaining Engineering	7.271
Payload Processing GSE Sustaining Engineering	7.653
Shuttle Carrier Aircraft	3.67

Table 4-32 Shuttle Support Equipment Costs (Source: 1994 Access to space study)

Annual reoccurring cost (CES 2.3.2.10) = 7.271 x (CES 2.3.1.2 + CES 2.3.1.3 + CES 2.3.1.4 + 2.3.1.9) / [Shuttle (CES 2.3.1.2 + CES 2.3.1.3 + CES 2.3.1.4 + CES 2.3.1.9)] + 7.653 x average payload in pounds / 23,923 + 3.67 x carrier aircraft x (vehicle dry weight / Shuttle dry weight) where carrier aircraft = 1 if included; 0 otherwise.

4.11.3 Aircraft Costing

Vehicle	FY05 $ per vehicle	Vehicle	FY05 $ per vehicle
A010	4,132	C141	6,221
B001	27,976	E003	30,382
B002	14,744	E004	28
B052	4,351	F015	4,905
C005	7,256	F016	10,058
C009	29,604	F117	1,320
C010	22,265	T001	3,852
C017	16,367	T037	2,513
C130	12,663	T038	1,293
C135	580	T043	1,991

Table 4-33 Replacement Ground Support Equipment (GSE)[40] (Source: AFI 65-503, Attachment 2-1)

Regression Equation:

Support equipment cost per vehicle = - 31,916 + 835 Number of control surfaces - 2.84 Wetted area + 7,289 SQR[Avionics weight] + 0.155 Vehicle dry weight

```
13 cases used

Predictor        Coef        StDev          T        P
Constant       -31916         9241      -3.45    0.009
CTRL SUR        835.2        152.0       5.49    0.001
WETAREA       -2.8418       0.5818      -4.88    0.001
SQR(AVWGT)       7289         2138       3.41    0.009
DRY_WGT       0.15458      0.04607       3.36    0.010

S = 3835        R-Sq = 86.9% Average = $10,125
```

Annual reoccurring cost (CES 2.3.2.10) = Support equipment cost per vehicle x Number Vehicles

4.12 ILS Management (CES 2.3.2.11)

4.12.1 Definition

Integrated Logistics Support (ILS) management costs consist of both nonrecurring and recurring costs associated with planning and implementing the logistics support system including repair management,

40 The yearly cost to replace organizational and intermediate common and peculiar GSE. GSE encompasses a wide range of items such as various test equipment, noise suppressers, generators, tow bars, simulators, and carts. The factors represent the cost of procuring, not repairing, both common and peculiar support equipment.

spares management, quality control, and administration of the logistics enterprise system.
ILS is the coordinated management and application of all the logistics elements needed for successful operational performance and maintenance of the vehicles and their equipment. In general, the main elements of ILS are maintenance, transportation, and supply planning and associated computer resources.

Alternate definition: ILS is a management function that provides planning, funding, and functioning controls which help to assure that the system meets performance requirements, is developed at a reasonable price, and can be supported throughout its life cycle. -- (Reference: Air Force Institute of Technology, Graduate School of Acquisition and Logistics.)

4.12.2 Shuttle Costing

Activity	FY05 $M	Head Count
Systems and Audit	1.15	13

Table 4-34 Shuttle ILS Cost (Source: 1994 Access to space study)

Shuttle Mode: The annual ILS management cost is assumed to be a percent of the Shuttle value based upon the sum of the other logistics support costs and the corresponding Shuttle logistics support costs.

Annual reoccurring cost (CES 2.3.2.11) = 1.15 x Annual reoccurring cost [(CES 2.3.2.1) + (CES 2.3.2.2) + ... + (CES 2.3.2.10)] / (Shuttle logistic support cost – 1.15)

4.12.3 Aircraft Costing

ILS costs have traditionally been computed as a fixed percentage of the sum of all the other logistics costs. The LCM used factors of 8 percent and 13 percent for nonrecurring and recurring costs respectively (Source: Logistic Cost Analysis Model, NAS1-18975, DRD-10, Rockwell International, September 1993).

Costs are based upon .08 (initial) and .13 (annual) times the sum of the other logistics support costs.

Initial cost (CES 2.3.2.11) = .08 x Initial cost [(CES 2.3.2.1) + (CES 2.3.2.2) + ... + (CES 2.3.2.10)]

Annual reoccurring cost (CES 2.3.2.11) =.13 x Annual reoccurring cost [(CES 2.3.2.1) + (CES 2.3.2.2) + ... + (CES 2.3.2.10)]

5.0 SYSTEM SUPPORT

5.1 System Support

System support consists of those functions required to support the general infrastructure including general management, planning, engineering, environmental programs, etc.

5.1.1 Air Force Cost Data

Table 5-1 shows the installation support costs (excluding military and civilian payroll) by MAJCOM and is used to estimate the MAJCOM non-pay base operating support costs per authorized military member. Installation support activities include: Child Development, Family Centers, Anti-Terrorism, Environmental Conservation, Pollution Prevention, Environmental Compliance, Minor Construction, Maintenance and Repair, Base Engineering Support (RPM), and Air Base Ground, Visual Information Activities, Demolition and Chemical Biological, Command & Base Communications, and Base Operations. These activities provide funding for base support functions, and engineering and environmental programs. The main objectives are to sustain mission capability, quality of life, workforce productivity and infrastructure support.

Major Cmd	FY05 ($K)	Authorizations	$ Per Authorization
AFSOC	$27,521	9,641	$2.85
AFMC	$743,498	85,022	$8.74
AETC	$362,875	74,973	$4.84
AMC	$258,576	57,395	$4.51
PACAF	$656,551	40,537	$16.20
ACC	$515,101	98,277	$5.24
USAFE	$607,631	33,497	$18.14
AFSPC	**$352,901**	**22,357**	**$15.78**
USAFA	$40,995	3,967	$10.33
Composite	$3,565,650	425,666	$8.38

Table 5-1 Installation Support Costs (Source: AFI 65-503 Table A56-1, Installation Support Non-Pay Cost Factors September 2000 adjusted for FY 2005)

The graph and fitted curve in Figure 5-1 was created from this data.

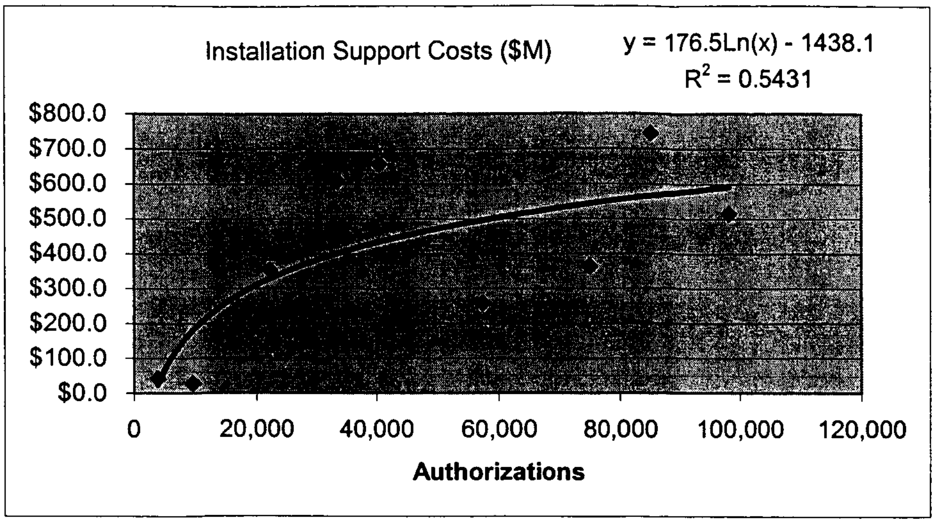

Figure 5-1. Support Cost versus Authorizations

The number of authorizations is estimated by scaling the Shuttle headcounts with cost as a scaling factor.

CES	Activity	Headcount	Shuttle Cost (FY05$M)
2.3.1	Operations	9,307	$1,419
2.3.2	Logistics Support	5391	$1,270
2.3.3	System Support	8955	$1,076
2.3.4	Program Support	6,753	$936
2.3.5	R&D	10,385	$1,644
	Total	40,791	$6,345

Table 5-2 Shuttle Headcounts (Source: 1994 Access to Space Study)

To determine the non-pay installation support cost, authorizations are first estimated from

Authorizations = 9307 x Annual recurring cost (CES 2.3.1) / 1419 + 5391 x Annual recurring cost (CES 2.3.2) / 1270 + 6753 x Annual recurring cost (CES 2.3.4) / 936 + 10385 x Annual recurring cost (CES 2.3.5) / 1644

Non-pay installation Support cost = 176.5 x ln(Authorizations) – 1438.1
If Non-pay installation Support cost < 0 then Non-pay installation Support cost = 0

To allocate this cost among the CES 2.3.3 cost elements, the percentages shown in Table 5-3 are used.

Program Elements:	FY 2003 Actuals	FY 2004 Estimate	FY 2005 Estimate	Average	Percent
Audio Visual Information Activities	$8,248	$8,635	$8,545	$8,476	
Child Development	$11,434	$11,986	$13,570	$12,330	
Environmental Compliance	$33,299	$33,474	$29,195	$31,989	
Environmental Conservation	$6,719	$6,656	$7,848	$7,074	
Family Support Centers	$3,149	$3,345	$3,355	$3,283	

Pollution Prevention	$9,726	$9,630	$10,738	$10,031	
Subtotal support	$72,575	$73,725	$73,251	$73,184	10.7
Base Operating Support	$198,807	$203,534	$203,232	$201,858	29.6
Restoration & Modernization	$22,566	$20,311	$44,294	$29,057	
Sustainment	$136,959	$124,658	$130,499	$130,705	
Real Property Services	$172,144	$172,716	$181,517	$175,459	
Subtotal facilities	$331,669	$317,685	$356,311	$335,222	49.0
Base Communications	$69,201	$70,484	$80,574	$73,420	10.7
Total	$672,253	$665,428	$713,369	$683,683	100

Table 5-3 Distribution of Base Support Costs (Source: Department of the Air Force Fiscal Year Fy 2004/Fy 2005 Biennial Budget Estimates, Operation and Maintenance, Activity Group: Space Operations, Base Support)

In order to estimate support personnel costs, the factors provided in Table 5-4 are applied to the total unit mission personnel estimated above. The medical factor is also applied against the BOS and facilities. The resulting BOS cost is then allocated to all but the facilities cost element using the Table 5-3 percents. Medical costs are placed in the support cost element.

	Base Operating Support	Facilities	Medical
Factor (max)	.15	.016	.023
Officer	.02	.02	.21
Enlisted	.81	.81	.62
Civilian	.17	.17	.17

Table 5-4 Base Support Personnel Fractions (Source: May study, Operating and Support Cost Estimates, A Primer)

Table 5-5 shows the allocation of the total BOS authorizations (.15 x authorizations) among the three cost elements derived using the factors shown in Tables 5-3 and 5-4.

	Support	Comm	BOS	Total
Percent	0.107	0.107	0.296	0.51
allocation	0.210	0.210	0.580	1
Officer	0.000629	0.000629	0.001741	0.003
Enlisted	0.025491	0.025491	0.070518	0.1215
Civilian	0.00535	0.00535	0.0148	0.0255
Total	0.031471	0.031471	0.087059	0.15

Table 5-5 Distribution of Support Personnel

5.2 Support (CES 2.3.3.1)

5.2.1 Definition

Support consists of the functions of Administration, Planning, Engineering, SRQ&A, and logistics management required to support site-wide functions.

- Administration includes the functions required to administer the program, finance, legal, resources.
- Planning includes the functions required to schedule the work to support the manifest.

- Engineering includes systems, sustaining, and field engineering tasks. Also the integration and design engineering.
- SR&QA includes preparing, planning and implementing safety programs; implementing and maintaining the Reliability, Maintainability and Quality Assurance Programs. This includes the functions associated with implementing and maintaining a PRACA system.
- Logistics management includes the administrative effort required to plan control and implement program.

AF Definition: Nonpay Base Operating and Support. This element includes support equipment, necessary facilities, and the associated nonpay variable costs specifically identified to base-level support functions for fixed installations and assigned mission units. This includes costs for supply, travel, automatic data processing support (nonfunctional), rent and other costs associated with comptroller, consolidated base personnel office, audiovisual services, social actions, judge advocate, command section, fuels management, and other base-support functions.

5.2.2 Shuttle Costing

Activity	$M
Orbiter Processing Support	31.63
SRB Processing Support	2.17
ET Processing Support	1.28
Administration	
Program Administration	13.90
Human Resources	9.57
MOD Directorate Office	3.70
Orbiter Support	64.93
Planning	
Operations Management	8.4
Integrated Work Control System (IWCS) Development	23.3
Engineering	
Sustaining Engineering & Launch Support	138.1
Systems Engineering/Support	14.4
LPS Engineering and Software	15.4
Instrumentation and Calibration	16.6
Logistics Engineering	4.1
MSFC Propulsion Systems Integration	44.3
JSC Engineering Directorate	91.5
Ames	7.7
Safety, Reliability, Maintainability and Quality Assurance	31.25
Total	$522.2

Table 5-6 Shuttle Support Costs (Source: 1994 Access to space study)

Annual reoccurring cost (CES 2.3.3.1) = (31.63 + 64.93) x (Nbr vehicles /4) x (Vehicle wetted area / 11,999) + (8.4 + 138.1 + 14.4 + 15.4 + 44.3 + 91.5 + 7.7 + 31.25) x Annual reoccurring cost (CES 2.3.1) / Shuttle operations cost + 4.1 x Annual reoccurring cost (CES 2.3.2) / Shuttle logistics cost +(13.9 + 9.57 + 3.7 + 23.3 + 16.6) x Annual reoccurring cost (CES 2.3.1 + CES 3.2.2) / Shuttle operations and logistics cost) +2.17 SRB + 1.28 ET where SRB = 1 if used, 0 otherwise; ET = 1 if used, 0 otherwise

5.2.3 Aircraft Costing

FY 2005 $ In Thousands	FY 2003 Actuals	FY 2004 Estimate	FY 2005 Estimate	Average
Audio Visual Information Activities	$8,248	$8,635	$8,545	$8,476
Environmental Compliance	$33,299	$33,474	$29,195	$31,989
Environmental Conservation	$6,719	$6,656	$7,848	$7,074
Pollution Prevention	$9,726	$9,630	$10,738	$10,031
Total	$57,992	$58,395	$56,326	$57,571
Average per installation	$7,249	$7,299	$7,041	$7,196

Table 5-7 Aircraft Support Costs (Source: Department of the Air Force Fiscal Year Fy 2004/Fy 2005 Biennial Budget Estimates; Operation and Maintenance, Activity Group: Space Operations, Base Support)

The AF support cost does not include engineering support other than as it applies to facilities or civil engineering. However, the PREVAIL model [28] provides a historical factor for computing engineering support cost which is 5% of launch, flight and recovery costs.

Engineering support cost = 0.05 x [(CES 2.3.1.9) + (CES 2.3.1.10) + (CES 2.3.1.11)]

Annual reoccurring cost (CES 2.3.3.1) = .107 x Non-pay installation support cost + support personnel cost + medical personnel cost + engineering support cost

5.3 Facility O&M (CES 2.3.3.2)

5.3.1 Definition

Facility costs consist of the costs of operation, maintenance, and modification of all facilities required to support the launch system including the launch and post launch cleanup. Shuttle values include GSE, SFE, and their spares; engineering, SR&QA, and logistics. Air Force data (aircraft) include costs for essential installation facility support for purchased utilities, utility plant operations, grounds maintenance, fire protection, crash rescue, snow removal and ice alleviation, entomological services, elevator maintenance/inspection, and rents and leases. Contracted engineering services include custodial services, refuse collection, corrosion control, sewer and waste systems, facility engineering and public works management, other installation engineering services and annual service requirements performed in-house or by contract.

5.3.2 Shuttle Costing

Facility Cost Categories	FY05 $M
Facility Operations and Maintenance	111.739
Modifications	17.73
LPS O&M	32.53
Facility/SE Engineering	25.00
Non-IWCS Hardware, Software and Maintenance and Support	2.04
Mission Operations Facilities	189.16
White Sands Test Facility	12.37
Total	390.569

Table 5-8 Shuttle Facility Costs (Source: 1994 Access to space study)

The Facility Operations and Maintenance cost data may be broken down as shown in Table 5-9.

Facility O&M Costs	FY05 $M
Facility O&M Support Operations	22.705
Facility Maintenance	30.103
Launch Equipment Shops (LES)	24.108
Facility Systems	6.378
Maintenance Service Contracts	4.847
Inventory Spares & Repair	2.679
Support Equipment	20.919
Total	111.739

Table 5-9 Shuttle Facility O&M Costs (Source: 1994 Access to space study)

The maintenance costs may be further broken down as shown in Table 5-10.

Facility Maintenance Costs	FY05 $M
OPF Maintenance	6.378
HMF Maintenance	1.786
VAB Maintenance	5.485
LCC Maintenance	0.765
MLP Maintenance*	
Transporter Maintenance	2.041
PAD A Maintenance*	
PAD B Maintenance*	
SLS Maintenance	0.510
CLS Maintenance	0.893
Logistics Facilities Maintenance	0.893
RPSF Maintenance	0.893
SRB Retrieval Vessel Maintenance	2.296
Miscellaneous Facility Maintenance	6.505
Dredging Operations	0.510
Processing Control Center Maintenance	0.510
OSB Maintenance	0.638
Total	30.103

Table 5-10 Facility Maintenance Costs (Source: 1994 Access to space study)

*Costs are accounted for under refurbishment CES 2.3.1.1)

The Facility modifications cost data may be further broken down as shown in Table 5-11.

Facility Modification	FY05 $M
OPF Modifications	2.424
HMF Modifications	0.128
VAB Modifications	0.893
LCC Modifications	0.255
MLP Modifications	0.893
Transporter Modifications	0.000
PAD A Modifications	0.638
PAD B Modifications	0.765
SLS Modifications	0.000
CLS Modifications	0.128
RPSF Modifications	0.128
Miscellaneous Facility Modifications	1.276
SE Modifications	0.765
LPS Hardware Modifications	9.056
Instrumentation & Calibration Modifications	0.000
Communication Modifications	0.383
PAD B Block Modifications	0.000
Total	17.73

Table 5-11 Facility Modification Costs (Source: 1994 Access to space study)

Table 5-12 lists the facilities supported under Mission Operations.

Mission Operations Facilities
Control Center Operations
Integrated Training Facility Operations
Integrated Planning System Operations
Shuttle Avionics Integration Laboratory (SAIL)
Flight Operations Trainer
Software Production/Software Dev. Facility
Mockup and Integration Laboratory (MAIL)
Control Center Systems Division
Integrated Planning System Office
Simulator and Training Systems Division
STSOC Material

Table 5-12 Mission Operations Facilities (Source: 1994 Access to space study)

The scaling factor is formed from the sum of those operational and logistics costs that correspond to activities that would generate facility requirements.

Annual reoccurring cost (CES 2.3.3.2) = [357.7934 + 12.37 Test Facilities
+ (6.378 + 2.424) x number Vehicle processing facilities /3 + (5.485 + .893) x number VAB / 2
+ .893 x number MLP /3 + (.638 + .765) x number Launch pads / 2
+ (2.296 + .51) x SRB] x Scaling factor

Scaling factor = [CES 2.3.1.2 + CES 2.3.1.3 + CES 2.3.1.4 + CES 2.3.1.7 + CES 2.3.2.1 + CES 2.3.2.6 + CES 2.3.2.7 + CES 2.3.2.10] / [Shuttle CES 2.3.1.2 + Shuttle CES 2.3.1.3 + Shuttle CES 2.3.1.4 + Shuttle CES 2.3.1.7 + Shuttle CES 2.3.2.1 + Shuttle CES 2.3.2.6 + Shuttle CES 2.3.2.7 + Shuttle CES 2.3.2.10] ($530.767M)

and Test Facilities = 1 if included; 0 otherwise and SRB = 1 if included; 0 otherwise

5.3.3 Aircraft Costing

FY2005 $ in thousands	FY 2003 Actuals	FY 2004 Estimate	FY 2005 Estimate	Average	Average per base
Restoration & Modernization	$22,566	$20,311	$44,294	$29,057	$3,632
Sustainment	$136,959	$124,658	$130,499	$130,705	$16,338
Real Property Services	$172,144	$172,716	$181,517	$175,459	$21,932
Total	$331,669	$317,685	$356,311	$335,222	$41,903

Table 5-13 AF Facility Costs (Source: Department of the Air Force Fiscal Year FY2004/FY2005 Biennial Budget Estimates: Space Operations, February 2004.)

Detailed Description: Facilities Sustainment, Restoration, and Modernization (FSRM) functions include demolition, sustainment, and restoration and modernization accomplished by contract and by an in-house workforce. This activity supports and maintains the primary space systems launch, tracking, and recovery complexes, Headquarters Air Force Space Command (AFSPC) at Peterson AFB, Colorado, the Cheyenne Mountain complex and other space tracking and support operations worldwide. The objective is to sustain mission capability, quality of life, and workforce productivity and to preserve the physical plant. Infrastructure support encompasses a variety of systems, services, and operations. The most significant categories receiving this support are sustainment and restoration and modernization of: Real Property Aircraft Maintenance Complexes, Aircraft Runways, Roads, and Dormitories. This activity supports facilities at eight bases. Real Property Services provides essential installation facility support for purchased utilities, utility plant operations, grounds maintenance, fire protection, crash rescue, snow removal and ice alleviation, entomological services, elevator maintenance/inspection, and rents and leases. Contracted engineering services include custodial services, refuse collection, corrosion control, sewer and waste systems, facility engineering and public works management, other installation engineering services and annual service requirements performed in-house or by contract.

Annual reoccurring cost (CES 2.3.3.2) = .49 x Non-pay installation Support cost + Personnel Costs

5.4 Communications (CES 2.3.3.3)

5.4.1 Definition

Communications includes all task required to operate and maintain communications for voice, data, and navigation. For Air Force costs (i.e. aircraft) this includes base communications consisting of the base telephone systems, maintenance of intra-base radio systems, base wire communications, official toll calls, Class B toll calls, and other base government-owned commercial communication requirements; dedicated leased long lines that provide connectivity to Air Force and DoD networks; Global Decision Support

Systems to support command and control of worldwide airlift/tanker mission requirements; Phase IV standard base level computer equipment; and secure voice teleconferencing command and control systems.

5.4.2 Shuttle costing

Activity	FY05 $M
Communications	25.13
Network Support	92.22
Total	$117.35

Table 5-14 Shuttle Communication Costs (Source: 1994 Access to space study)

To establish a scaling factor, it is assumed that the communications costs are proportional to the total operations and logistics cost.

Annual reoccurring cost (CES 2.3.3.3)
= $117.35 x Annual reoccurring cost (CES 2.3.1 + CES 3.2.2) / (Shuttle operations and logistics cost)

5.4.3 Aircraft costing

Air Force communications support is the peculiar support equipment, necessary facilities, and the associated marginal costs specifically identified to base telephone systems, nontactical radio systems, wire communication services, intrabase radio systems, and base-level commercial communications requirements. The element does not include costs of AUTOVON, AUTODIN, and leased long line communication services.

FY 2005 in $1,000	FY 2003 Actuals	FY 2004 Estimate	FY 2005 Estimate	Average	Average per base
Base Communications	$69,201	$70,484	$80,574	$73,420	$9,177

Table 5-15 Base Communications Cost

Annual reoccurring cost (CES 2.3.3.3) = .107 x Non-pay installation Support cost + Personnel Costs

5.5 Base Operations (CES 2.3.3.4)

5.5.1 Definition

Base Operations costs are the portion of costs generated by the launch system to provide support services such as installation security, fire protection, grounds maintenance, etc. Air Base Operating Support consists of transportation, base security forces, comptroller, staff judge advocate, claims; dining facilities, lodging, contracting services, chaplain, administration, mess attendant and equipment maintenance contracts, postal services, data processing, airfield and air operations, furnishings management, and other authorized service activities.

5.5.2 Shuttle Costing

Activity	FY05 $M
Base Operations Contract (BOC)	26.53
Weather Support	3.70
JSC Center Ops	8.04
Total	$38.27

Table 5-16 Shuttle Base Operating Support Cost (Source: 1994 Access to space study)

It is assumed that there is a primary installation comparable to KSC. Any additional installations (locations) supporting the mission will be a tenant organization comparable to JSC and MSFC.[41]

Annual reoccurring cost (CES 2.3.3.4) = [(26.53 + 3.70) + 8.04 (number Installations 1)] / 2 x Annual reoccurring cost (CES 2.3.1 + CES 3.2.2) / (adjusted Shuttle operations and logistics support cost)

5.5.3 Aircraft Costing

FY 2005 $ In Thousands	FY 2003 Actuals	FY 2004 Estimate	FY 2005 Estimate	Average	Average per base
Base Operating Support (BOS)	$198,807	$203,534	$203,232	$201,858	$25,232

Table 5-17 Aircraft BOS (Source: Department of the Air Force Fiscal Year FY2004/FY2005 Biennial Budget Estimates: Space Operations)

Annual reoccurring cost (CES 2.3.3.4) = .296 x Non-pay installation Support cost + Personnel Costs

41 The JSC base operating cost is split with MSFC. Additional installation operating costs are picked up in Program Support (CES 2.3.4)

6.0 PROGRAM SUPPORT AND R&D

6.1 Program Support

6.1.1 Definition

Program Support costs are the cost of all functions and activities occurring at the program level at both HQ and NASA Centers. These include program management, systems engineering and integration, program office support, financial management and procurement, contract management, and institutional activities.

6.1.2 Shuttle Costing

Activity	FY05 $M
Total Program Office/Headquarters	229.98
Total Institution	609.21
Program Management Support	96.69
Total	$935.88

Table 6-1 Shuttle Program Support Costs (Source: 1994 Access to space study)

The program office/headquarters includes activities such as Management, SE&I, Flight Analysis, Engineering Integration, Payload Integration, STSOC Mission Integration Support, Landing Site Support, Configuration Management, Mission Verification & PRCB Support, system Integration, ADP Facilities & Operations, MIC Support, Publications, Information and Management Systems, ADP Equipment, Program Office Support, Program Control Activities, Systems Engineering & Integration Support, Support Services, Auditing Services Tax, and the EEE Parts Program.

Institution consists of installation operation including both direct and indirect labor and travel for the installations shown in Table 6-2.

It is assumed that program management is proportional to the (adjusted) operational and support costs.

Installation	Institution	PMS	Total
Headquarters	73.854		
KSC	248.989	25.384	274.373
MSFC	86.355	25.511	111.866
JSC	187.379	42.093	229.472
SSC	12.628	3.699	16.327
Total	609.21	96.69	

Table 6-2 Shuttle Program Costs by Installation (Source: 1994 Access to space study)

Annual reoccurring cost (CES 2.3.4) = [(229.98 + 73.854 + 274.373) + (111.866 + 229.472) x (number of Installations – 1) / 2 + 16.327 Test Facility] x Annual reoccurring cost (CES 2.3.1 + CES 3.2.2) / (adjusted Shuttle operations and logistics support cost) where Test facility = 1 if used; 0 otherwise

6.1.3 Aircraft Costing

The activities in Table 6-3 funds managerial and supporting activities for Air Force Space Command.

A. Program Elements:	FY 2003 Actuals	FY 2004 Estimate	FY 2005 Estimate	average
1. Acquisition And Management Support	$84,070	$92,998	$90,919	$89,329
2. Engineering & Inst Supt-AFSPC	$9,689	$11,899	$19,591	$13,726
3. Mgt Headquarters - Space Command	$28,606	$31,797	$32,303	$30,902
4. Operational Hq - Space	$4,905	$5,927	$7,829	$6,220
5. Service Spt Combatant Hq-Spacecom	$7,586	$9,312	$69	$5,656
6. Service Spt To Spacecom Activities	$8,644	$10,618	$14,010	$11,091
Total	$143,501	$162,551	$164,722	$156,925

Table 6-3 Space Command Program Support Costs (Source: Department of the Air Force Fiscal Year FY2004/FY2005 Biennial Budget Estimates; Operation and Maintenance, Active Forces Budget Activity: Operating Forces; Activity Group: Space Operations; Detail by Subactivity Group: Other Space Operations)

Annual reoccurring cost (CES 2.3.4) = 157 x Authorizations (CES 2.3.1 + CES 3.2.2) / 25,000

A corresponding source of data for aircraft is the System Program Offices (SPO) budgets within the Aeronautical Systems Center (ASC) at Wright Patterson AFB. ASC is responsible for management of aeronautical systems acquisition of aircraft and other aeronautical systems, as well as life support systems. Included are costs to pay civilian personnel, travel, transportation, contractual services, supplies and equipment. Not included are funds for Research, Development, Test and Evaluation (RDT&E) activities that are funded in the RDT&E appropriation.[42] As one of several product centers within the Air Force Materiel Command (AFMC), the center conceives, designs, develops, integrates and acquires AF systems, subsystems, and equipment.[43]

6.2 R&D

6.2.1 Definition

Research and Development includes those on-going efforts to develop better operating capabilities but do not relate directly to normal operation requirements.

6.2.2 Shuttle Costing

Activity	FY05 $M
Total Other NELV Elements	0.00
Pre-Planned Product Improvement	786.00

[42] The Air Force Operational Test and Evaluation Center (AFOTEC) mission is to manage the Air Force Operational Test and Evaluation (OT&E) program in accordance with Air Force and Department of Defense (DoD) policy and guidance. OT&E provides an evaluation of the operational capabilities of a weapon system and identifies deficiencies in the system before designated production and acquisition decisions.

[43] Air Force Program Management Office (PMO) budgets were not available.

Total STS Capability Development	857.81
Total	$1643.81

Table 6-4 Shuttle R&D Costs (Source: 1994 Access to space study)

Pre-Planned Product Improvement consists of the following:	
Orbiter Improvements	
Orbiter Production (Schedule B)	
Orbiter Support	
Extended Duration Orbiter	
Long Duration Orbiter	
SSME Production	
	Program Support
	Test Support
	Flight Certification Ext.
	Product Improvement/Producibility
	Alternate Turbopump Integration
	Technology Test Bed
	Flight Certification Ext. Hardware
	Block II Controller
	Phase II & P/H
Project Support	
	Science & Engineering
	Propellants
	Other
Launch Site Equip. & Mission Ops Cap.	
Launch Site Equipment @ KSC	
APA	
White Sands Test Facility	
Space & Life Sciences	
Mod Equipment Replacement & Upgrades	
FCOD Aircraft Acquisition and Mods	
Support Services	
Level II Ops Integration	
Level II Management Integration	
Safety & Obsolescence Upgrades	

Table 6-5 Preplanned Product Improvement Activities (Source: 1994 Access to space study)

Annual reoccurring cost (CES 2.3.5) = [$786 + $857.81 If capability development planned] x Annual reoccurring cost (CES 2.3.1 + CES 3.2.2) / (adjusted Shuttle operations and logistics support cost)

6.2.3 Aircraft Costing

FY05 $M	2003 Actual	2004 estimate	2005 estimate	Average
A10	$11.17	$30.05	$23.03	$21.42
B1B	$153.73	$89.64	$60.61	$101.33
B2	$236.65	$169.14	$249.80	$218.53
F16	$7.91	$98.00	$101.54	$69.15
F15E	$72.12	$124.81	$98.46	$98.46

F22	$66.69	$319.17	$361.40	$249.09
F117	$3.78	$14.91	$30.24	$16.31
E4B	$48.31	$44.85	$11.39	$34.85
U2	$24.57	$47.50	$89.45	$53.84
C5	$279.06	$353.26	$308.86	$313.72
C17	$158.83	$187.48	$203.56	$183.29
KC135	$1.94	$3.21	$1.10	$2.08
KC10	$20.54	$2.33	$18.81	$13.89
Average	$83.49	$114.18	$119.86	$105.84

Table 6-6 AF R&D Costs (Source: Department Of The Air Force, Fiscal Year FY2005 Budget Estimates, Research, Development, Test And Evaluation (RDT&E), Systems Development and Demonstration (Budget Activity 05) and Operational Systems Development (Budget Activity 07))

A regression analysis indicated a good correlation between the average age of an aircraft and the average budget over a three-year period using AF RDT&E data. The initial analysis showed the C-5 as an outlier. As a result, the final results displayed in Figure 6-1 do not include the C-5 aircraft.

Aircraft	Avg Age (FY03)*	Average RDT&E budget (FY03 - FY05)
A10	21.8	$21.42
B1B	16.1	$101.33
B2	9.1	$218.53
F16	12.4	$69.15
F15E	17.3	$98.46
F22	1.8	$249.09
F117	17.2	$16.31
E4B	29.3	$34.85
U2	20.2	$53.84
C5	21.8	$313.72
C17	4.5	$183.29
KC135	42.6	$2.08
KC10	18.7	$13.89

Table 6-7 Average Ages Of Aircraft (Source: AFI 65-503, E16-FY03)

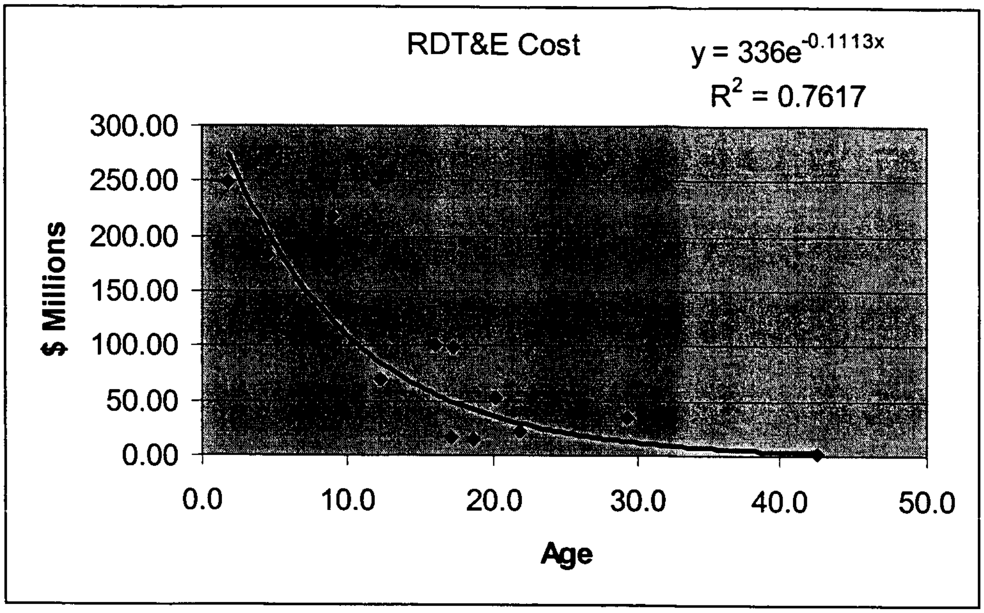

Figure 6-1 Age of Aircraft versus RDT&E Costs

Annual reoccurring cost (CES 2.3.5) = $\sum_{i=1}^{\text{System Life}} 336\ e^{-0.1113i} / \text{System Life}$

7.0 IMPLEMENTATION

In order to put into practice the methodology presented in this research, a computerized application is necessary. The following two models provide an integrated framework for performing a conceptual design study and implements the methodology resulting from this and earlier research.

Reliability & Maintainability Analysis Tool (RMAT) - computes vehicle and subsystem reliabilities, maintenance hours, maintenance personnel, spares, and turn times based upon vehicle design and performance parameters. RMAT is derived from Shuttle and Air Force reliability and maintainability data.

Operations & Support Cost Analysis Tool (OSCAT) - provides a means of estimating operations and support costs using a combination of cost estimating relationships (CERs) obtained from several cost models and cost data sources, Shuttle O&S costs, and engineering cost estimates based upon various cost factors.

The RMAT model would be utilized first in order to obtain maintenance workload, vehicle reliabilities, turn-times, and spares levels. These along with many of the RMAT input parameters are then used by OSCAT in computing the cost elements.

Detailed documentation on the use of both models may be found in their respective User's Manuals and will not be repeated here [references 18 & 19].

8.0 CONCLUSION AND RECOMMENDATIONS

The cost estimation approach outlined in this report provides both a pessimistic (Shuttle based) estimate and an optimistic (aircraft) estimate. Users have the flexibility to use either or a weighted average of the two for each of the 27 cost elements. In addition, for any cost element, users may override the computed value and apply their own independently derived estimate. Learning curves, inflation factors, and discounting provide additional life cycle costing flexibility.

When used with the companion Reliability and Maintainability Analysis Tool (RMAT), the number of additional input parameters and model specifications has been kept at a minimum.

Several recommendations have emerged from this research.

1) Minor adjustments should be made to the cost element structure (CES) with several of the definitions made more precise. For example, refurbishment should be better defined, the transfer CES should be combined with Integration Operations and possibly combine Integration and Processing Operations.
2) Individuals knowledgeable in the original costing exercise should reevaluate the Shuttle Access-to-Space costing. This evaluation should be conducted from three perspectives. First, the cost element mapping from the original cost breakdown structure to the CES used in this research should be reviewed to insure that the mapping is correct. Second, the breakdown of each cost element between fixed (annual) costs and variable (flight driven) costs should be confirmed. Third, a search should be made to identify cost sources that may be more current and more accurate than the 1994 study but still relevant for this costing activity.
3) A continuing effort should be made to find alternate sources of relevant Air Force Operations and Support cost data and to break down in more detail the current cost data where possible. This is particularly useful in the operations cost area in general, and documentation and support costs specifically.
4) The methodology should be enhanced to include a risk assessment. This can be accomplished by treating the Shuttle scaled costs as a pessimistic value, the aircraft computed estimate as an optimistic value, and the weighted average of the two as the most likely cost. With these three parameters determined, a triangular distribution can then be applied to each cost element estimate. Through a Monte Carlo simulation, confidence intervals can be established for each cost element, each subtotal, and the overall life cycle cost. A similar approach may be feasible with RMAT although its implementation may be somewhat more involved.
5) Additional reports may prove to be useful particularly in displaying details of certain cost elements as well as allocating costs to particular subsystems where possible.
6) Lastly, users should exercise the costing methodology specifically to identify areas of improvement and additional capabilities that would be useful in a cost estimating effort.

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APPENDIX A
GLOSSARY and ACRONYMS

Base-Year Dollars – dollars expressed in their value at the time of the specified base year of a program as if they were all expended during that year.

Constant-Year Dollars – dollars expressed in their value at the time of any specified year, which may, but does not have to be base year. Also called "constant dollars." Within the costing methodology, constant year dollars are always expressed at the base-year.

Crew Ratio – the number of authorized flight and mission crew members per vehicle. The crew ratio times the number of vehicles gives the total number of flight crew and mission crew personnel assigned to train and perform the flight missions.

Economic Life—The period of time over which the benefits to be gained from a project may reasonably be expected to accrue to the NASA. It is the shortest of physical, technological or mission life.

Life-Cycle Cost—The total cost to the government for a system over its full life, including the cost of development, procurement, operation, support, and disposal. O&S LCC factors attempt to account for the flow of costs throughout the economic life of a system. Life-cycle factors represent the cumulative average of actual prior year data, from initial operation through an average economic life, projected out to some future budget year.

Present Value—The net value of a flow of funds, expressed as a single sum of dollars; effectively, the sum of money equivalent to all current and future flows. Calculated by multiplying the net cost figure for each year by the corresponding discount factor, and summing the results.

Then-Year dollars – base year dollars deflated or inflated through the use of indices to show total money needed at the time expenditures are actually made.

SHUTTLE RELATED TERMS

External Tank (ET)—the largest and heaviest (when loaded) element of the Space Shuttle, the ET has three major components: the forward liquid oxygen tank, an unpressurized intertank that contains most of the electrical components, and the aft liquid hydrogen tank. *(Source: NASA,Shuttle Reference Manual)*

Orbiter—divided into nine major sections: the forward fuselage, which consists of upper and lower sections that fit clamlike around a pressurized crew compartment; wings; midfuselage; payload bay doors; aft fuselage; forward reaction control system; vertical tail; orbital maneuvering system/reaction control system pods; and body flap. *(Source: NASA,Shuttle Reference Manual)*

Solid Rocket Boosters (SRBs)—primary elements of each booster are the motor (including case, propellant, igniter and nozzle), structure, separation systems, operational flight instrumentation, recovery avionics, pyrotechnics, deceleration system, thrust vector control system and range safety destruct system. *(Source: NASA, Shuttle Reference Manual)*

Space Shuttle Main Engine (SSME)—the main engines are reusable, high-performance, liquid-propellant rocket engines with variable thrust. The propellant fuel is liquid hydrogen and the oxidizer is liquid oxygen. The propellant is

carried in separate tanks in the external tank and supplied to the main engines under pressure. *(Source: NASA, ShuttleReference Manual)*

Space Shuttle System—consists of four primary elements: an orbiter spacecraft, two solid rocket boosters (SRBs), an external tank to house fuel and oxidizer, and three Space Shuttle main engines. *(Source: NASA, Shuttle Reference Manual)*

Space Transportation System (STS)—the overall Shuttle program is called the Space Transportation System. *(Source: NASA, Shuttle ReferenceManual)*

Acronyms

ET – External Tank

HMF - Hypergolic Maintenance Facility

JSC - Johnson Space Center
The Mission Control Center at Johnson Space Center directs all Space Shuttle missions. The Shuttle astronauts primarily train, work and plan their missions at Johnson Space Center

KSC - Kennedy Space Center
Kennedy Space Center's primary business is preparing and launching a variety of space vehicles and payloads as well as the home of Space Shuttle operations. As the world's only launch site for the Space Shuttle, Kennedy prepares the vehicles for each mission, operates each countdown and manages end-of-mission landing recovery activities.

LCC - Launch Control Center
A four-story structure located adjacent to the VAB. Contains the LPS.

LPS - Launch Processing System
To maintain the desired launch rate, Space Shuttle vehicles must be assembled, checked out and launched as quickly and inexpensively as safety requirements permit. This pace is made possible by the LPS - a highly automated, computer- controlled system that oversees the entire checkout and launch process.
[Reference: http://science.ksc.nasa.gov/facilities/lps.html]

MSFC - Marshall Space Flight Center
The Marshall Center manages all Space Shuttle propulsion elements, including the Main Engine, External Tank and Solid Rocket Boosters.

OMDP – Orbiter Maintenance Down Period
Extensive maintenance and modification originally scheduled to occur once every 3 years for each orbiter. May be conducted at one of the O(F bays or in the Rockwell facility at Palmdale, California

OPF – Orbiter Processing Facility

PAI – Primary Aircraft Inventory
The number of aircraft authorized for the unit

PE – Program Element, used for budgeting by the AF

SPDMS – Shuttle Processing Data Management System

SSC - Stennis Space Center
The Propulsion Test Directorate at Stennis Space Center oversees one-of-a-kind national test facilities.

SSME – Space Shuttle Main Engines

STS – Space Transportation System

VAB – Vehicle Assembly Building

APPENDIX B
TECHNICAL DATA

Space Shuttle stack height: 56.14 m (184.2 ft)

Orbiter alone: 37.23 m (122.17 ft) long

Wingspan: 23.79 m (78.06 ft)

Mass at liftoff: 2,041,000 kg (4.5 million lb)

ET 751,000 kg

SRB 2 x 590,000 = 1,180,000 kg

Thrust at lift-off 34.8 MN:

SSMEs 3 x 1.8 = 5.4 MN

SSRBs 2 x 14.7 = 29.4 MN

Mass at end of mission: 104,000 kg (230,000 lb)

Maximum cargo to orbit: 28,800 kg (63,500 lb)

Orbit: 185 to 643 km (115 to 400 statute miles)

Velocity: 27,875 km/h (7.7 km/s, 17,321 mi/h)

Passenger Capacity: 10 Astronauts (crews other than 5 to 7 are uncommon, 8 was largest crew)

APPENDIX C
SELECTED COST MODELS

Although several are somewhat dated, the following models continue to have some relevancy to the development of cost estimating relationships for conceptual design space vehicles. These models are:

1) AFI 655-03 (former AFR 173-13)
2) Conceptual Design and Analysis of Hypervelocity Aerospace Vehicles: Volume 5 - Cost
3) Conceptual Design and Analysis of Hypervelocity Aerospace Vehicles: Vol 3. Cost
4) Life Cycle Cost User's Manual (HVLCCM)
5) Modular Life Cycle Cost Model (MLCCM) for Advanced Aircraft Systems
6) NATO: Software Life Cycle Costing
7) Naval Fixed Wing Aircraft Operating and Support Cost Estimating Model
8) PREVAIL: Algorithms for Conceptual Design of Space Transportation Systems
9) Strategic Missile (Minuteman) Operating and Support Cost Factors (STRAMICE)
10) Unmanned Space Vehicle Cost Model, Sixth Edition (SD TR-88-97)

AFI 655-03 (former AFR 173-13), reference 1, is a compilation of cost data appropriate for anyone doing O&S life cycle cost analysis for current (and former) aircraft used in the US Air Force. The data includes military and civilian salaries, support costs by aircraft, and inflation indices. The use of these costs factors is mandated by the regulation to comply with the CAIG requirements. The most important aspect of AFI 655-03 is that it contains a generic O&S cost model. The CORE cost model has seven major cost categories with up to four levels of indenture (ie. 7.1.2.2.1 Officer), for a total of 93 entries. The main levels are: Unit Mission Personnel, Unit Level Consumption, Intermediate Maintenance (external to unit), Depot Maintenance, Contractor Support, Sustaining Support, and Indirect Support. The instruction is updated regularly.

References 2 and 3 are the same document separated by three years, number 3 being the later of the two. This is an application of the standard modular life cycle cost model (MLCCM) to a hypervelocity vehicle. The vehicle can be manned or unmanned. The model was verified with shuttle data obtained from outside the contractor for the shuttle (congressional testimony, NASA documentation, etc.) and was found to predict the LCC of the shuttle relatively closely. This reference contains cost and manpower estimating relationships for R&D, production, and O&S life cycle cost for a hypervelocity vehicle. the model was designed to be run as a spreadsheet where the costs associated with each stage of the system is developed separately and then consolidated into a system summary of the life cycle costs over the life of the system. There are only minor revisions to the first document in the second.

Reference 4 documents the operation of the life cycle cost model developed in references 2 and 3 and is derived from reference 5. It explains how multiple stages (segments) of the vehicle can be costed separately using the appropriate CER or using actual cost data, if it is available, and then how the costs are to be accumulated in the appropriate subsystem. This accounting of costs complies with the guidelines of the CAIG. The program itself is implemented as a spreadsheet under LOTUS.

The modular life cycle cost model (MLCCM), reference 5, is the standard LCC model used by the US Air Force to comply with the CAIG directives. Most of the LCC models used in the Air Force are derived from this model. The model has more than 100 different data inputs and encompasses all phases of the life cycle (except disposal) of an avionic system life cycle. The model uses the type of material used in

the different aircraft structures to determine the costs of materials, production, and repair based upon a comparison to standard aluminum practices. The shortcoming is the inability to predict disposal costs, but neither does any other appropriate LCC model.

Reference 6 is an attempt by NATO to develop a uniform method to estimate the life cycle cost of computer systems (software and hardware) used in C^3I systems. This reference surveys the different types of models used in developing the cost estimates, which include PRICE-S, COCOMO, etc. The driver used in estimating the other output parameters (facilities, personnel, etc.) is lines of code (LOC). The different models use different methods in developing this simple parameter, depending upon which computer language is used and the complexity of the application. The more sophisticated models also use the size of computer, the application to be hosted, if hardware is to be developed and if it is to be developed in tandem with the software, and what level of experience the team creating the software/hardware has in similar projects. The costs are in international accounting units (IAUs) to reduce the bias involved with selecting a particular monetary unit.

Reference 7 updates a Naval parametric Operating and Support estimating model using the CAIG guidelines for O&S cost analysis. The model updates 14 direct cost elements using 15 different aircraft types which represents the bulk of the Navy and Marine fixed-wing aircraft. Both linear and semi-log (log-linear) cost estimating relationships were developed for each of the direct cost elements. The presentation of the regression equations is the most complete of any of the models. The data points used, the residuals, outliers, and the fitting parameters are shown for each CER, this enables rapid verification of the CER or the development of different (exponential, etc.) relationships. The operational requirements and the maintenance philosophy used by the Navy prevents the direct application of many of the developed CER's for use in this study. The completeness of the data analysis in developing the CER's provides a basis of comparison between those developed for a space system and the CER's developed from the NAVY data. This allows a validity check of the space developed CER's by analogy with the NAVY CER's. The NAVY CER's can be used as a bound on CER's developed for conceptual space systems.

Reference 8 is geared toward a transportation system to place man and/or material in space. The costs are for three different configurations of vehicle (winged, aerodynamic and ballistic) with different launch scenarios. The model can be implemented on a PC using a spreadsheet.

Reference 9 is a summary of the cost model used by the former Strategic Air Command (SAC) to do a high level estimation of the costs associated with the strategic nuclear missile fleet. This high level fast response model relies heavily on readily available information contained in AFI 655-03 (former AFR 173-13) as input to the model. This model will run on a simple PC-based spreadsheet.

Reference 10 is the USAF Space Division's detailed analytic cost estimating relationships derived from eighteen unmanned space vehicles. The CER's are derived from regressions equations encompassing recurring and nonrecurring costs across system phases. The system phases include research and development, and production of space hardware from the component level (when available) through final assembly including normal program costs (like overhead and G&A). Some systems have over 3000 account names which were then incorporated into larger systems. This costing system is organized to be implemented as a PC based spreadsheet.